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The Institution of Electrical Engineers

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The Society of Telegraph Engineers

VICTORIA EMBANKMENT, LONDON W.C.

FOUNDED 1871

"TO PROMOTE THE GENERAL ADVANCEMENT OF ELECTRICAL AND TELEGRAPHIC SCIENCE AND ITS APPLICATIONS."

EDITED BY P. F. ROWELL, SECRETARY.

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## CORRIGENDA.

p. 18, col. 2, line 22 : For "time" read "type."

p. 25, col. 1, equation (3) : For  $\left(1 + \frac{1}{\infty}\right)$  read  $\left(1 + \frac{1}{\infty}\right)^{\infty}$ .

p. 58, col. 1, last line : For "maximum values" read "minimum values."

p. 144, col. 2, line 25 : For  $\left(\frac{S_1 S_c}{\sigma_1 \sigma_c L_1 L_c}\right)$  read  $\left(\frac{S_1 S_c}{\sigma_1 \sigma_c L_1 L_c}\right)^{\frac{1}{2}}$ .

p. 251, col. 1, lines 22 and 23 : should read Vent area 82,000 ; Watts 2,300  
Outside area 25,000 ; Watts 3,750 | 10,320

*Justin Price*



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*Robert E. Porto.*

PRESIDENT 1915-16

# THE JOURNAL OF

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### INAUGURAL ADDRESS.

By CHARLES P. SPARKS, President.

*(Address delivered 18 November, 1915.)*

I am conscious of the great honour my fellow members have conferred on me in electing me President of this Institution, and during my year of office my best endeavours will be devoted to upholding the position of the Institution and the interests of its members.

Before dealing with the main subject of my Address, I propose referring to three points:—

#### (1) NATIONAL SERVICE.

The last Presidential Address\* called attention to the importance of every individual member working "in the best way he can for the good of King and Country." After 15 months of war on an unprecedented scale the present need is not less urgent, the last recruit and the last round of ammunition being the deciding factor.

While the bulk of our 7,000 members are engaged in maintaining the public services or, directly or indirectly, the manufacture of munitions of war in comparative safety, our hearts go out to the 1,150 members of the Institution who are on active service in answer to the national call.

The last Annual Report of the Council† dealt in detail with the work done by the Institution under the able direction of my predecessor, and it is the earnest desire of the Council to take all possible steps to enable our organization to be of still further use in the national service.

#### (2) THE INSTITUTION.

I take this opportunity to impress upon all the younger members of our profession the importance of joining the Institution, not only as a means of education throughout their professional life, but to enable them to keep in touch with the leaders of the many branches of our industry. I know of no more important step in my professional life than the benefits received from becoming a member of

this Institution (then the Society of Telegraph Engineers and Electricians) in 1885.

#### (3) NECESSITY FOR MANUFACTURING PROFIT.

As one-half of my career has been spent in the manufacture of electric supply plant, and the other half as engineer to electric supply undertakings, I desire to say a few words on a subject of special interest to all sections of the Institution.

It is sometimes suggested that commercial matters should not be dealt with by engineers, who should confine themselves to technical questions. I disagree with this view, and believe that the commercial engineer is just as much a recognized member of our profession as a pure scientist.

Now, as to the acceptance of the lowest tender, whether it be British or foreign, it must always be remembered that the onus of development and the successful carrying out of a contract are borne by the contractor, and that if a reasonable margin of profit is not secured, the contractor cannot in the long run do his duty by the purchasers. First, the contractor is crippled, being unable to make provision for development, since without profit new capital cannot be attracted; but, what is more serious, provision cannot be made for improvements, without which we cannot keep pace with our world competitors.

No industry has suffered more from competition than our own, and the continued acceptance of the lowest tender in the past has so limited the resources of certain sections of the manufacturing industry that only a minority of manufacturers have been able to make a reasonable return to their shareholders, and, owing to the restricted profits in recent years, inadequate amounts have been spent on developing new inventions.

The national interest would be better served by encouraging private enterprise to develop invention, by allowing manufacturers a reasonable margin of profit, than by securing—for the moment only—slight fractional

\* *Journal I.E.E.*, vol. 53, p. 1, 1915.  
† *Ibid.*, vol. 53, p. 722, 1915.

reductions in the costs of public service undertakings through acceptance of the lowest tender, which is not necessarily always the most favourable.

#### ELECTRICITY SUPPLY.

I propose to follow the example of many of your Past Presidents by reviewing the position of that section of the industry with which I have been closely associated.

- (I) The effect of legislation on our industry.
- (II) Electricity supply in the Metropolis.
- (III) The main engineering features which have contributed to improved results since 1888.
- (IV) The direction of further progress.

#### (I) EFFECT OF LEGISLATION.

The electric supply industry became possible by the invention of the carbon-filament lamp in 1879 by Sir Joseph Swan in England and Mr. T. A. Edison in the United States. This invention was of far-reaching importance to the public health, providing for the first time in the world's history a means of illumination without vitiating the atmosphere.

The even greater possibilities for the distribution of power by employing electric motors had been demonstrated by Gramme in 1873, but were not recognized until many years after the electric supply business had been established, primarily to supply electricity for lighting.

No industry received earlier recognition by Parliament than ours. Unfortunately, the advantages of encouraging private enterprise were disregarded. In the case of gas supply, after competition had been tried over a long period, monopolies were granted to private enterprise to supply gas over large areas, the price being controlled by a sliding scale connecting the price of gas and dividends. This method of operation has resulted in the greater part of the Metropolis being supplied by two gas companies representing the amalgamation of 19 smaller undertakings (the Gas Light and Coke Company supplying an area in and around London of 125 square miles, from six main stations all supplied in bulk from the main down-river station at Beckton, 12 miles from the centre of the Metropolis). Under this method of control, gas is supplied at a low price, at the same time allowing the gas companies to earn such dividends that there has been little difficulty in financing the undertakings.

In spite of this precedent, Parliament in passing the Electric Lighting Act of 1882 decided that the unit of area in the case of our industry should be a parochial one.

In 1882 the (London) Metropolis of 117 square miles was divided into 42 local-government areas (since amended by the London Government Act of 1899 to 29). In each of these areas the Local Authority had the first right to supply electricity, and could obtain without difficulty a Provisional Order giving perpetual rights; but if a company wished to supply an area, they could only do so by obtaining either a licence for seven years by consent of the Local Authority, or, subject to the approval of the Board of Trade, a Provisional Order for 21 years with a chance of renewal for 7-year periods, the undertaking being liable to purchase by the Local Authority on terms most unfavourable to the operating company.

In consequence of this enactment, by the end of 1888 public supply was being given by only three companies under licences in Great Britain, and no supply was being given under any Provisional Order, the numbers of Orders and Licences issued up to the end of 1888 being as follows:—

	Provisional Orders	Licences
Company ... ..	55	7
Local Authority ...	15	2

The effects of legislation in thus stifling the new industry in Great Britain were far reaching. Our American and Continental competitors seized the opportunity to forge ahead in developing this new industry, which they had placed on a successful commercial footing. In the meantime manufacturers in Great Britain, unable to proceed with the equipment of undertakings operating under statutory powers, had either to turn their attention to the equipment of separate works with lighting and power, or to operate without statutory powers by using overhead wires, permission for these being secured by private way-leaves of uncertain tenure. By this method of development the electric supply industry was started on unsound lines in this country, and the effects of this false start are still felt.

Many attempts were made to modify the Act of 1882 and to secure similar terms for our industry to those possessed by the gas companies, but although the Local Authorities had done nothing to develop the powers conferred on them by the Act of 1882, the municipal interest was too strong to allow private enterprise a fair field in spite of the efforts of Lord Thurlow, the Earl of Crawford, and many other public men, and of the strongly worded petitions of the Institution of Civil Engineers and our Institution (then the Society of Telegraph Engineers and Electricians).

The Act of 1888 modified the Act of 1882 in four important particulars.

- (1) It doubled the life of private undertakings by extending the period of franchise from 21 to 42 years, with possible periods of extension of 10 years in place of seven.
- (2) It modified the terms of compulsory purchase, but still left them sufficiently ambiguous to make it difficult to extend private undertakings during the latter years of their franchise.
- (3) The consent of each Local Authority was required before the Board of Trade granted any Provisional Order, the Board of Trade being empowered to dispense with such consent on special grounds.
- (4) A Local Authority or another company might obtain a competing Provisional Order in the area of any operating company.

In spite of many efforts another 21 years had to elapse before further general legislation was secured.

The Act of 1909 gave substantial concessions, namely,

- (1) The right of compulsorily acquiring land for power stations.
- (2) The power to break up streets outside the area of supply (rendering it possible for the first time to place the power station outside the area supplied).

- (3) The power to give supply in bulk.
- (4) The right to supply railways, tramways, etc., outside the area of supply.
- (5) Association between supply undertakings.
- (6) The prohibition of unauthorized undertakings competing with statutory undertakings.

Following the Act of 1888 a large number of applications were made by companies for powers to supply the more central area of the Metropolis. Before deciding which Provisional Orders should be reported to Parliament, the Board of Trade in March 1889 appointed Major Marindin, R.E., to hold an Enquiry and report on the whole question.

Several of the companies applied for powers to supply large areas. Among these was the London Electric Supply Corporation, Limited, who, in addition to desiring powers to supply in a number of districts, wished to secure general powers to supply in bulk to any Local Authority which desired to distribute electricity in its own area.

The bulk of the applications received were from companies who proposed to supply low-pressure continuous current from a number of generating stations.

The London County Council (created in 1888) took no part in these proceedings, but, following the receipt of Major Marindin's report which was submitted to them for observation before being adopted by the Board of Trade, made the following suggestions :—

- (1) In the interests of the public, competition is desirable under proper restrictions.
- (2) The provision of the bulk-supply powers asked for by the London Electric Supply Corporation is doubtful, but, if given, these should in no case be acted upon without the consent of the London County Council.
- (3) To ensure healthy competition between the companies no amalgamation or working agreement between companies should be permitted without the consent of the London County Council.
- (4) It would be to the advantage alike of the public and of the companies that there should be one uniform system of regulation and control throughout the entire area of London.
- (5) The Council considers that it should be the authority to whom should be given the power of purchase, in all cases, at the expiration of a specified period, as it would be manifestly impossible for any single Vestry or District Board to purchase a large undertaking supplying many parishes.

The Marindin Enquiry and the Report of the Board of Trade, covering the Model Order, made it clear that private enterprise was still to be hampered :—

- (1) Although the objection of the Local Authority to the granting of powers to a company could be overruled by the Board of Trade (Act of 1888, Section 1), the Report decided that a Provisional Order could be refused if the Local Authority expressed its intention to undertake supply. This process of freezing out private enterprise was successful in many cases for several years, thus retarding development.

- (2) Competition was encouraged between company and company in London, and was emphasized in the Report in spite of the known disadvantages of "dead" capital in distributing mains and the greater interference with the streets.
- (3) No company supplying in the Metropolis was allowed to associate with any other company, or to purchase or acquire another undertaking.
- (4) Bulk-supply powers were refused.
- (5) As each company was strictly confined to its allotted area, all power stations had to be erected in the area of supply.

The proposal of the London County Council that they should be the Purchasing Authority was rejected, and it was not until 1908, when the companies obtained the right of association under the London Electric Supply Act, that the London County Council were constituted as the Purchasing Authority for the whole of the company undertakings in 1931 in substitution for the separate Local Authorities.

The main results of the Marindin Enquiry were :—

The splitting-up of London among a number of separate undertakings, each with one or more generating stations, the majority operating with low-tension continuous current although it was known that the limiting distance for transmission from continuous-current stations was at that time half a mile. The main technical reason for this decision was the unsuitability of the alternating-current system for motive power, although it was obvious from the character of the central area that the demand for motive power could never attain important dimensions in that part of the Metropolis.

While immense trouble was taken in settling the method of supplying London in detail and in dealing with all local questions, the more important question of supplying London as a whole was disregarded.

The Model Order issued after the close of the Marindin Enquiry did not deal with the question of system, the Report stating, "It would, therefore, be wisest in my opinion, to give fair scope to all the proposed systems, all of which are capable of being worked, and it may be predicted with tolerable certainty that whatever system proves itself to be the best under all circumstances will eventually be adopted by all."

The difficulty and expense of change of system was not foreseen.

In consequence of the decision to split up the Metropolis into many areas, when new demands arose for electric traction in the areas of several supply undertakings the traction undertakings naturally erected independent generating stations.

Thus badly equipped by legislation, the industry started in 1889 to engage in competition with well-established gas undertakings operating under perpetual powers.

#### (II) ELECTRICITY SUPPLY IN THE METROPOLIS.

Unfortunately, owing to the legislation previously referred to, this area has been subdivided between so many electrical undertakings that the question of general supply cannot be considered from an engineering point of view. The present position arises through a series of initial mistakes, and future improvement is more a matter of

adjusting numerous municipal and other vested interests, than an engineering question.

Since 1882 two names stand out in special prominence in attempts to rectify the position. The first is that of Mr. S. Z. de Ferranti, who advised the group now known as the London Electric Supply Corporation, Limited, which commenced operations without Parliamentary Powers in 1884. This group at the time of the amending Act of 1888 desired statutory powers to supply in a large area in the Metropolis from a down-river station, by means of 10,000-volt transmission mains, the pressure being reduced at main sub-stations for distribution to consumers at low pressure. Powers were also desired to supply electricity in bulk to any Local Authority who wished to distribute in its own area, Mr. Ferranti basing his scheme on the sequence of development which had taken place in the case of the gas companies.

While Mr. Ferranti's scheme was handicapped by many engineering difficulties due to the necessary development of large generators, 10,000-volt transmission mains, switch-gear, and transformers, it was further hampered by the refusal of the Board of Trade to grant bulk-supply powers and by allowing competition in the main area allocated to this company.

Owing to the difficulty of co-ordinating the many separate interests created by the Acts of 1882 and 1888, and the fixed idea of our legislators that all interests were subservient to the interests of Local Authorities, no serious attempt to rectify this chapter of errors was made until 1904-5, when Mr. Charles Merz brought forward his epoch-making scheme to provide for the future electricity supply of this important area. The main outlines of this scheme were:

The erection of three main power stations to supply the Metropolis—

- (a) In bulk to the authorized undertakers then existing;
- (b) Railways, tramways, and large consumers;
- (c) Power in detail, and lighting up to 20 per cent of the total supply to individual consumers.

The area consisted of the Metropolis and certain adjoining districts.

A maximum price of 1½d. per unit; dividends on a sliding scale depending on the average price (the average price taken as 3d. per unit, with a standard dividend of 8 per cent); if the average price exceeded 1d. per unit, no dividend.

The Bill as introduced had no provision for purchase. During the Parliamentary proceedings terms of purchase at the end of 42 years, or at subsequent periods of 10 years, on terms more favourable than those in the 1888 Act, were agreed with the London County Council.

While Mr. Merz succeeded in getting the Bill of the Administrative County of London Company passed by Committees of both the Lords and Commons, finally securing during the Enquiry the adhesion of all the companies and several of the important Local Authorities in the area, the great length of the Enquiry left only three days for the final stages (usually formal) in the Commons. The activity of a few private Members sealed the fate of this Bill and, notwithstanding the general benefits that would have resulted, the clock was again set back, certainly for 10 years, the further expansion of the individual under-

takings rendering the successful development of any complete scheme more difficult and more expensive each succeeding year.

At the end of 1888, the electric supply undertakings in the Metropolis consisted of four company undertakings (three of which were operating without Parliamentary powers), no supply being given by any municipal undertaking.

The four companies in question were as follows:—

(1) The Cadogan Electric Lighting Company, purchased by the Chelsea Electricity Supply Company, Limited, in 1893.

This Company supplied consumers in parts of what are now the boroughs of Chelsea and Kensington with continuous current at 100 volts from battery sub-stations charged from high-pressure continuous-current overhead mains, automatic switches being used to transfer the batteries from the charging to the supply mains.

(2) The Kensington and Knightsbridge Electric Lighting Company, supplying in part of Kensington under licence, continuous current being supplied to consumers at 100 volts from a station and batteries by means of underground mains.

(3) Sir Coutts Lindsey & Company, transferred to the London Electric Supply Corporation, Limited, in 1880, supplying the West End areas in London, including parts of what are now the city of Westminster and the boroughs of Marylebone and Chelsea.

The single-phase system was used, current being generated at 2,400 volts, 83 cycles, and consumers being supplied through overhead cables from separate transformers at 100 or 50 volts. The supply was given from two 600-kw. generators erected at the Grosvenor Gallery. The Deptford station was then under construction. This station was designed to operate at 10,000 volts and to transmit electrical energy, partly by means of overhead conductors and partly by underground mains laid on the railways, to various centres in London.

(4) The Oxford-street Electric Light Company, purchased by the Metropolitan Electric Supply Company in 1889, supplying parts of what are now the city of Westminster and the borough of Marylebone. This company employed overhead cables, and alternators generating current at 2,000 volts, 100 cycles, and it supplied individual consumers through transformers at 100 volts.

Owing to the difficulties of metering, no record of the units sold at this period is available.

Table 1 illustrates the progress made by the supply undertakings operating in London and giving a general supply apart from traction.

It will be noted that six years after the passing of the 1888 Act 10 supply companies were operating in the Metropolis, and it was not until these undertakings had been established by private enterprise that the Local Authorities, who had had it in their power since 1882 to secure perpetual rights to supply their own areas, commenced their operations; in fact, 12 years after the passing of the 1882 Act only one Local Authority was giving a supply in the Metropolis.

In the earlier stages of the industry when the supply was almost entirely confined to lighting, the average price was 6d. per unit. Ten years later when the number of units sold had increased tenfold and electricity was commencing

to be used for other purposes, the average price was reduced to 3½d.; whilst after a further period of 10 years, when the number of units sold had increased to some 27 times over the 1894 figures, the average rate had fallen to slightly under 2d. per unit.

Direct comparison of the prices charged by the Companies and Local Authorities is not possible. The Western and Central areas, where the principal demand is for lighting, are supplied entirely by the companies, and, although the average rate for the companies appears to be 24 per cent higher than that charged by the Local Authorities, a correct comparison can only be made when the relative proportions of lighting and power supply are known.

TABLE 1.

*Revenue from Sale of Electricity.*

	Units sold	Revenue from Sale of Electricity	Average Revenue per Unit sold
In 1894—			
Companies (10) ...	13,487,400	£339,000	5'90d.
Local Authority (1) ...	719,500	15,930	5'32d.
Totals ...	14,206,900	£352,830	5'96d.
In 1904—			
Companies (13) ...	109,113,000	£1,630,100	3'59d.
Local Authorities (13) ...	27,353,200	309,000	3'24d.
Totals ...	136,466,200	£1,990,100	3'52d.
In 1914—			
Companies (13) ...	211,709,500	£1,866,900	2'12d.
Local Authorities (14) (excluding Woolwich) ...	122,733,200	875,500	1'71d.
Totals ...	334,442,700	£2,742,400	1'97d.

TABLE 2.

*Capital Expenditure.*

Companies (14) at 31 December, 1914 ...	15,036,000
Local Authorities (14) at 31 March, 1914 ...	9,777,500
	£21,813,500

Progress during the first six years after 1888 was at the rate of 2·3 million additional units sold per annum, during the next 10 years 12 million additional units per annum, and during the last 10 years 20 million additional units per annum, although the use of the more efficient metal-filament lamp increased the light obtainable per unit more than threefold.

The density of the sales for general supply in the Metropolis, apart from those for traction, is now about 3 million units per square mile, 45 million units being used annually per square mile in the area of densest demand.

General supply is now being given in the Metropolis (an area of 117 square miles) by 28 separate undertakings, the areas supplied and the respective outputs in 1914 being shown in Table 3.

	Square miles
Area scheduled in Provisional Orders and supplied by 13 Companies ...	70'25
Competitive area between companies included in the above ...	11'87
Net area supplied by Companies ...	64'38
Area supplied by 14 Local Authorities ...	54'47
Bethnal Green (work in hand) ...	1'19
	55'60
	120'04
Companies and Local Authorities in competition ...	3'14
Total ...	116'90 square miles

The effect of allowing so many undertakings to operate in this area is shown by the following figures:—

METROPOLIS.	Total
<i>Number of separate undertakings.</i>	
General supply in the Metropolis ...	28
Traction supply in the Metropolis ...	10
	— 38
<i>Number of power stations.</i>	
Supply undertakings ...	38
Traction ...	10
	— 48
<i>Number of different frequencies.</i>	
Supply undertakings ...	8
Traction (3) (additional to above) ...	1
	— 9

In view of the successful results obtained in this country outside the Metropolis by concentration and the recognized practice of the rest of the world in allowing one authority to operate over a large area from a minimum number of power stations, there is little to be said on the London question from an engineering point of view; but in spite of the extreme difficulty in carrying through any scheme dealing with the whole area, it is clear from the results obtained elsewhere that London will be divided eventually for electricity-supply purposes into a reasonable number of areas, even if a scheme embracing the whole Metropolis is not carried through.

The two main difficulties to be met when approaching this matter from an engineering point of view are as follows:—

(1) Owing to the large sums invested by a number of separate undertakings in small power stations and special distributing systems, any comprehensive scheme must suffer a disadvantage in the first instance due to the added cost of—

- (a) New high-pressure network, and
- (b) Cost and loss in conversion plant.

From past experience distributing systems have been the only part of a supply undertaking which has not shown serious obsolescence, and there is now every reason

TABLE 3.

TABLE 3.

COMPANIES.						Area of Supply in Metropolis, Square miles	System of Generation
Year ended 31 December, 1914							
Units sold							
Brompton and Kensington Electricity Supply Co.						0.94	1-phase, 83 $\sim$ , 2,000 volts
Charing Cross, West End and City Electricity Supply Co. ... ..						1.95	3-phase, 50 $\sim$ , 10,000 volts, and C.C. (medium pressure)
Chelsea Electricity Supply Co. ... ..						1.03	C.C. (medium pressure)
City of London Electric Lighting Co. ... ..						1.38	C.C. (medium pressure), and 1-phase, 100 $\sim$ , 2,000 volts
County of London Electric Supply Co. ... ..						22.72	3-phase, 50 $\sim$ , 10,000 volts; 2-phase, 50 $\sim$ , 6,000 volts, and C.C. (medium pressure)
Kensington and Knightsbridge Electric Supply Co.						1.13	C.C. (medium pressure)
London Electric Supply Corporation ... ..						15.71	3-phase, 25 $\sim$ , 6,600 volts, and 1-phase, 83 $\sim$ , 10,000 volts
Metropolitan Electric Supply Co. ... ..						3.15	2-phase, 60 $\sim$ , 10,000 volts, and 2-phase, 60 $\sim$ , 1,000 volts
Notting Hill Electric Lighting Co. ... ..						2.04	C.C. (medium pressure)
St. James' and Pall Mall Electric Light Co. ... ..						0.25	C.C. (medium pressure)
South London Electric Supply Corporation ... ..						0.15	2-phase, 50 $\sim$ , 3,000 volts
South Metropolitan Electric Light and Power Co.						17.39	2-phase, 50 $\sim$ , 3,000 volts
Westminster Electric Supply Corporation ... ..						2.41	C.C. (medium pressure)
Totals ... ..						76.25	
Central Electric Supply Co. ... ..						Giving a bulk supply to the St. James', Westminster, and Chelsea Companies	
Kensington and Knightsbridge and Notting Hill Electric Lighting Companies (Joint) ... ..						Giving a bulk supply to the Kensington and Notting Hill Companies ...	
							3-phase, 45 $\sim$ , 6,000 volts
							3-phase, 45 $\sim$ , 5,250 volts
LOCAL AUTHORITIES.							
Year ended 31 March, 1914							
Units sold							
Battersea ... ..						3.37	C.C. (medium pressure)
Bermondsey ... ..						2.15	C.C. (medium pressure)
Fulham ... ..						2.66	2-phase, 50 $\sim$ , 3,000 volts
Hackney ... ..						5.14	C.C. (medium pressure) and 3-phase, 50 $\sim$ , 6,000 volts
Hammersmith ... ..						3.57	1-phase, 50 $\sim$ , 2,200 volts
Hampstead ... ..						3.54	1-phase, 90 $\sim$ , 2,100 volts
Islington ... ..						4.83	1-phase, 50 $\sim$ , 2,200 volts
Poplar ... ..						3.64	3-phase, 50 $\sim$ , 6,000 volts, and C.C. (medium pressure)
St. Marylebone... ..						2.30	C.C. (medium pressure), and 3-phase, 50 $\sim$ , 6,000 volts
St. Pancras ... ..						4.21	C.C. (medium pressure), and 3-phase, 50 $\sim$ , 5,300 volts
Shoreditch ... ..						1.03	C.C. (high and medium pressure)
Southwark ... ..						0.99	C.C. (medium pressure)
Stepney ... ..						2.76	3-phase, 50 $\sim$ , 6,000 volts
Stoke Newington ... ..						1.35	3-phase, 50 $\sim$ , 10,000 volts (bulk supply)
Woolwich (figures not available) ... ..						12.93	3-phase, 50 $\sim$ , 6,000 volts, and C.C. (medium pressure)
Bethnal Green (supply to commence in 1915) ... ..						1.19	3-phase, 50 $\sim$ , 6,000 volts (bulk supply)
Totals ... ..						55.66	

to estimate the return on the necessary expenditure in any new high-pressure network over a period sufficiently long to allow the undertaking to develop, rather than to look on the immediate result.

(2) Reliability of supply is of the first importance and of far greater importance than the provision of a supply at a minimum cost. It is therefore argued that it would be unsafe to supply the Metropolis from a few stations, special objection being taken to any scheme which commences by adding one new power station of considerable magnitude.

It will be agreed that adequate safety can be secured with far less than the present number of power stations (38 in number), and as most of the individual undertakings are being supplied by a single power station unconnected with any other undertaking, the general safety of supply would be improved if the separate undertakings were interconnected and supplied from a suitable number of modern power stations, each capable of dealing with demands of not less than 100,000 kilowatts. A commencement could be made with one station to supplement the supply from existing stations, and as the less efficient of these passed gradually out of use the main power station would be supplemented by a second and further stations as required.

Apart from public advantages of a co-ordinated supply working in the direction of a unified system with standard pressures of supply, and of the cheapening of plant owing to the greater demand for standard apparatus, and also of the lowering of the price per unit, there are two main factors that render a scheme of consolidation of the first importance, namely, economy in fuel, and the removal of power stations from the more densely populated areas.

### (III) MAIN ENGINEERING FEATURES.

While many inventions of value have resulted in improving the reliability of supply and in greater economy of production, progress is primarily due to the following improvements:—

- (1) Three-phase transmission.
- (2) Lowering of frequency.
- (3) Parallel working of alternators.
- (4) Development of the steam turbine and improved condensing plant.
- (5) Improved steam-raising plant.
- (6) Paper-insulated lead-covered cables.
- (7) Conversion of alternating to continuous current by rotary converters.
- (8) Development of reliable meters.
- (9) Metal-filament lamps.
- (10) Reduction in the first cost and the improved control of motors.

(1) *Three-phase transmission.*—Before the discovery of the 3-phase system by Galileo Ferraris and Nicola Tesla between 1885 and 1888, and its development by C. E. L. Brown and Dobrovolski, no transmission system was available capable of giving a general supply for all purposes. Single-phase alternating-current systems working at high pressure could supply lighting demands over a large area, whereas the continuous-current systems of transmission were unsuited to operate at high pressure, and

each continuous-current power station could only serve a limited area.

The economy in the first cost of 3-phase generators and transmission mains, and the ease of transformation of alternating currents by static transformers, combined with the invention of the induction motor, provided a system which enabled one undertaking to serve every class of demand in a large area.

(2) *Lowering of alternating frequency.*—The original alternating-current systems in this country were started for lighting supply and, owing to the difficulty of operating under statutory powers, consumers were supplied through overhead wires by separate transformers.

To keep down cost and to raise the efficiency, frequencies of 80 to 100 cycles per second were selected. Although not recognized at the time, the choice of these high frequencies made the development of single-phase alternating-current motors almost impossible. Alternating-current systems were unable to supply motive power until they commenced operating at frequencies ranging from 40 to 50. Long before any general change took place in this country, low frequencies had been adopted by C. E. L. Brown in Switzerland for low-speed generators driven by water power, and by Zipernowski who developed low-speed alternators direct-coupled to reciprocating engines.

Although 50 cycles has now been adopted as the standard frequency of supply for all purposes outside special transmissions or single-phase railway work, the effect of developing alternating-current systems on a wrong basis has not yet been eradicated.

(3) *Parallel working of alternators.*—The theory of the parallel working of alternators was described by Mr. H. Wilde in 1868 and by Dr. Hopkinson in 1882 (following his tests on the parallel operation of de Meriten's magneto machines, which were worked in parallel or run as synchronous motors), but the general parallel working of alternators was a matter of difficulty up to 1889. At that date, while the possibility of the parallel working of several types of alternators had been demonstrated, there was so much difficulty in operating machines in parallel that all the alternating supply companies in this country operated with alternators supplying separate groups of feeders, this method requiring complicated switchboards with a multiplicity of air-break switches to transfer or re-group the feeders as the load varied.

Zipernowski, whose alternators were constructed for direct coupling to low-speed engines, had found little difficulty in coupling low-frequency alternators in parallel, even when these differed in size and were driven by engines running at various speeds; but no material progress was made in the operation of alternators in parallel as standard power-station practice until after Mr. W. M. Mordey\* laid down the principles and demonstrated the theory by the practical parallel working of the alternators of his design. This pioneer work of Mr. Mordey at once had a far-reaching effect on power-station design and methods of working. It improved the reliability of the supply and lowered the operating cost by enabling the running plant to be worked at its most economical rating; it also showed the possibility of con-

\* W. M. Mordey, "Alternates-current Working," *Journal I.E.E.*, vol. 18, p. 388, 1889.

verting single-phase alternating currents into continuous currents by the use of synchronous motor-generators.

(4) *Steam turbine and condensing plant.*—The development of the steam turbine, due to Sir Charles Parsons of Newcastle, together with the adoption of superheated steam and suitable condensing facilities, have entirely changed the character of supply undertakings. It has enlarged their scope by increasing the possible size of operating units, has greatly reduced the first cost of generating and boiler-house plant and buildings, and has lowered operating cost.

To obtain the best results from steam turbines an ample supply of cold condensing water is essential; and when this is available, modern condensing plant is capable of maintaining a vacuum of 97 per cent (29 to 30 in. vacuum) of the theoretical value in the turbine casing, as compared with the 25 to 30 in. vacuum (85 per cent) normally used with reciprocating engines.

The use of turbo-generators enables a watt-hour to be generated in large power stations supplying diversified demands for 20 to 25 B.Th.U. (say  $1\frac{1}{2}$  to 2 lb. of average coal per unit), as compared with 100 to 150<sup>6</sup> B.Th.U. (or 8 to 12 lb. of average coal per unit) originally required in the small stations using non-condensing reciprocating engines supplying lighting demands.

It is interesting to compare the above results now obtained with Colonel R. E. Crompton's estimate of 1891 of future probable results before the development of the condensing steam turbine, namely, 36·25 B.Th.U.† per watt-hour generated ( $2\frac{1}{2}$  lb. of Welsh coal, 14,500 B.Th.U. per pound) with plant working continuously at full output.

In the early days of the industry the average size of the generator in lighting stations was 100 kilowatts, generators rated at 500 kilowatts being exceptional. The maximum size of turbo-generators is not yet in view; machines rated at 30,000 and 35,000 kilowatts and made by the General Electric Company (U.S.A.) are at work, while machines of still larger capacity are being designed. The upper limit in the size of generators is at present fixed by the extent of the system to be supplied and the limitations of the method of control, rather than by any limitations in the design of the turbine or electric generator.

(5) *Improved steam-raising plant.*—The main improvement in steam-raising is the universal use of large boilers of the water-tube type, combined with superheaters and mechanical stokers using small coal of medium calorific value, as compared with small boiler units of various types, hand-fired with coal of high calorific value.

Large power stations now use boilers in which the superheater and economizer form an integral part of the boiler, on normal output each boiler evaporating up to 50,000 lb. of steam per hour at 200 to 250 lb. per square inch pressure, the steam being superheated 200 to 250 degrees F., as compared with boilers evaporating 8,000 to 10,000 lb. of steam at 80 to 150 lb. pressure.

Great progress has been made in furnace design and in mechanical stokers, thereby enabling small coal of comparatively low calorific value to be efficiently and smokelessly burnt. This has resulted in the average

efficiency in conversion of the heat energy of the coal being raised from 65 to 85 per cent on test and from 50 to 75 per cent under operating conditions, with a material saving both in the cost of fuel and in labour.

Also, due to mechanical stoking, boilers now give their full output efficiently and continuously for long periods, compared with the fluctuating output in the case of hand-fired boilers due to the necessity of cleaning fires. This factor is of prime importance in reducing the amount of boiler power required.

Again, the use of small coal enables the entire coal supply to be handled mechanically, and the development of the suction ash-conveyor has reduced to a minimum the amount of labour required in the boiler house.

As a result of the improved thermal efficiency of the boiler house and resulting low temperature of the gases, mechanical draught has become a necessity, the old difficulties of induced-draught plant, due to action of the hot gases on the fan and casing, not occurring with the lower temperature at which the gases are discharged from the boiler.

Instead of duplicate cast-iron steam ranges with copper bends, single steel mains are used, while the continuous flow of steam required by turbines, as compared with the intermittent flow of steam with reciprocating engines, has further reduced the area of steam pipes exposed to condensation.

The decrease in the number of operating units and the simplified steam range have directly reduced the stand-by losses in the boiler house and steam piping.

The increase in size and the improved design of water-tube boilers and accessories have resulted in the space occupied by the boiler-house plant being reduced to one-fifth of that required for an equal evaporation of steam 30 years ago.

Through the introduction of turbo-driven machinery, which requires no internal lubricant, the durability of the boiler plant has been much improved, one of the main difficulties with boilers used in conjunction with reciprocating engines being the presence of small quantities of grease in the condensed feed-water.

The maintenance of the boiler-house efficiency, which is of the first importance owing to fuel being the main operating cost, has been materially assisted by the development of temperature, CO<sub>2</sub>, and draught recorders, together with simple apparatus for determining the calorific value of fuel.

(6) *Paper-insulated lead-covered cables.*—The invention and development by Mr. Ferranti of the paper-insulated lead-covered cable has not only reduced the cost of transmission and distribution, but has largely increased the reliability of operation. In the early days of the industry, owing to the lack of information as to new requirements, the practice of telegraph engineers was followed, underground cables being insulated with rubber, or gutta-percha, and drawn into iron pipes; while for low-pressure systems requiring conductors of large section, bare copper strips mounted on insulators, or bitumen-insulated cables laid solid or drawn into bitumen concrete conduits, were used.

These methods are now only used exceptionally, all transmission cables being paper-insulated, lead-covered, armoured, and laid direct in the ground; while for dis-

\* R. E. CROMPTON, "Cost of Electrical Energy," *Journal I.E.E.*, Vol. 25, p. 506, 1894.

† R. E. CROMPTON, "The Cost of the Generation and Distribution of Electrical Energy," *Minutes of Proceedings of the Institution of Civil Engineers*, vol. 100, p. 2, 1891.

tributing purposes in the more central areas, paper-insulated lead-covered cables drawn into conduits are largely used. When it is considered that some 40 per cent of the capital outlay in the electric supply business is due to distribution, of which the cost of cable represents the greater proportion, the importance of this development is apparent.

(7) *Conversion of alternating current to continuous current by rotary converters.*—No conversion was possible in the early stages owing to the want of an alternating-current motor, and it was not until the difficulties of this development were overcome by a reduction of frequency that any general supply of continuous current could be given from an alternating-current system.

The first method of conversion was by means of motor-generators, either of the synchronous or induction type, the efficiency of conversion ranging from 85 to 88 per cent at full load.

The present method of conversion for a general supply is by rotary converters. These were first developed some 25 years ago in the United States for supplying traction systems, a frequency of 25 being standardized for transmission. Although satisfactory results were obtained for traction purposes with rotary converters working at this frequency, it was not until 1905 that satisfactory 50-cycle rotary converters were developed. This development was rendered possible by the introduction of interpoles, which allowed higher speeds to be used, thus securing reasonable spacing for commutation.

The development of the 50-cycle rotary converter has resulted in reducing the space occupied by transforming plant to one-half of that required by motor-generators; the first cost has been reduced to between one-half and two-thirds, and the efficiency of conversion has been raised to 94 per cent at full load.

(8) *Development of reliable meters.*—The metering of electricity was a great difficulty in the case of early undertakings. The first meter developed for continuous-current supply was of the electrolytic type. No meters were available for alternating-current systems and electricity was sold by annual contract.

Initially the development of the continuous-current meter appeared to be a simpler problem than the metering of alternating currents, and three types were soon developed, which are still in use, although greatly improved in construction and accuracy. These were as follows:—

Ampere-hour meters—Ferranti	..	Mercury motor-meters
"	"	Hookham...
"	"	Aron ... Clock type
Watt-meter—Thomson	...	Motor meter

No alternating-current meter, however, was developed until 1889, when, following the discoveries of Ferraris and Tesla, the rotary-field type of meter was developed by Schalenberger in the United States.

All alternating-current meters are of the motor type worked on the rotary-field principle. The absence of commutation and of collection of current has proved an enormous advantage in maintaining their accuracy, and although the development of the continuous-current meter appeared simpler in the early stages, more difficulty is now experienced in maintaining its accuracy over a given period than with the alternating-current type.

No method of metering energy has been brought to greater perfection than the metering of electrical energy, and the ease and accuracy of measurement have played a great part in enabling losses to be analysed and improvements made by increasing the efficiency of apparatus and the operation of the system.

The standard of accuracy laid down by the Board of Trade for large meters is  $2\frac{1}{2}$  per cent + from 1/20th to 1/10th load, and  $2\frac{1}{2}$  per cent + or — from 1/10th to full load. There is little difficulty in maintaining modern meters within these limits of accuracy for periods of five years, owing to the moderate speeds of rotation at full load.

As an instance of close calibration and accuracy over a considerable period, I give the reading of three motor meters, the power factor of the supply varying from 0.8 to unity and the demand from 25 to 60 per cent of the rated capacity of the meters.

	Meter (1)	Meter (2)	Meter (3)
Number of units registered	1,955,700	1,945,800	1,952,300
Mean reading—units ...		1,951,266	
Error from mean—units...	+ 4,434	— 5,466	+ 1,034
" " " %	+ 0.23%	— 0.28%	+ 0.05%

(9) *Metal-filament lamps.*—The carbon-filament lamp used at 100 volts in 1888 was rated at 60 watts for 16 mean spherical candle-power, the average lamp consuming 4 watts per candle-power. Until 1906, when the metal-filament lamp was developed for commercial use, the main development of the carbon-filament lamp had been in the direction of increasing its flexibility by introducing lamps of smaller candle-power and increasing the voltage to allow the use of 250-volt lamps in consumers' premises; but no material reduction in the energy required per candle-power-hour had taken place.

The introduction of the metal filament resulted, however, in increasing the candle-power-hours derived from one unit of electricity threefold to 800 candle-power-hours per unit, lamps of small candle-power being manufactured for pressures up to 250 volts.

The recent development of incandescent lamps with nitrogen-filled bulbs has again more than doubled the number of candle-power-hours obtainable per unit, the figure now being 2,000. The standard sizes of lamps of this type now in use are: for 100 volts, 60 watts (120 candle-power) and upwards; for 250 volts, 120 watts (240 candle-power) and upwards, smaller units of light being available where lower pressures can be obtained by transformation.

These improvements in the efficiency of incandescent lamps have resulted in increasing the standard of illumination and have largely increased the use of indirect lighting.

Although the number of units sold by some supply undertakings showed a marked decrease when metal-filament lamps were first introduced, the lowering of the cost of illumination at once resulted in increased business, which, owing to the growth in the number of consumers, has placed the supply undertakings on a more secure foundation.

Another important result of the introduction of the metal-filament lamp is that, owing to the high temperature at which the filament is worked, it is much less sensitive to fluctuations in pressure.

The Board of Trade Regulations issued in 1889 required the pressure of supply at consumers' terminals to be maintained within 4 per cent. At any point of the system where the above variation was worked to, the light given by carbon-filament lamps varied between the limits of  $-20$  and  $+25$  per cent. With the same pressure variation the metal-filament lamp has much reduced the variation, the limits being  $-14$  and  $+16$  per cent. With the present type of half-watt lamp, the variation is further reduced to  $12$  per cent  $\pm$  or  $-$ .

This characteristic of the metal-filament lamp, added to the absence of the blackening of the bulb, has much improved the quality of the lighting and has materially reduced the difficulties met with during the hours when the distributing network is heavily loaded.

(10) *Motors.*—The high efficiency of conversion from electric to mechanical power in the motor as originally developed left little room for improvement. The main efforts of designers have been devoted to reducing the weight and thus lowering the first cost, which has fallen 50 per cent in motors of moderate size during the last 15 years.

The other direction of advance has been in improved reliability, reducing the cost of maintenance.

Little further improvement can be expected in efficiency, which, for motors of moderate power, speed, and voltage, reaches 85 per cent.

The development of the induction motor, with its advantages of close speed-regulation and absence of commutation, has been largely responsible for electric driving being used in many industrial concerns in preference to other forms of power.

#### (IV) DIRECTION OF FURTHER PROGRESS.

In the light of our present knowledge there are four main reasons why we should expect a large further expansion in the general supply, apart from the extension of electric traction and the use of electrical energy for electrochemical purposes. These reasons are as follows:—

- (1) Necessity for fuel economy.
- (2) The extension of lighting.
- (3) The increased range of transmission.
- (4) Domestic use of electricity.

(1) *Necessity for fuel economy.*—The economical use of fuel has been hindered in this country by its low price. Until some other primary source of power and heat is found, the world may be considered to be living on its capital, i.e. the stored energy in the coal, and to be using fuel wastefully to the prejudice of future generations.

Only a fraction of the total coal consumed is at present used for centralized source of supply of power and heat; the principal future economy in fuel is to be found in increasing the use of such centralized supply to allow the most efficient use to be made of the world's coal supplies. To attain this economy, large capital outlay is required on plant for converting the heat energy of the coal into electricity; but the present apparent lower cost using fuel inefficiently at a large number of isolated points retards progress in the direction of centralization, as immediate results are often only considered.

The fuel-saving by using a centralized supply is due to

the reduction of stand-by losses and to the higher efficiency of large generators and boiler plant when worked under skilled supervision. The fuel-saving under average conditions from a central scheme as compared with isolated plants is not less than 75 per cent. With the gradual increase in the cost of fuel it is unquestionable that all main supplies for power and heat will be obtained in the future from centralized sources.

In the absence of any prospect of the development of an economical system of storage for electricity, which would at once raise the present load factors of from 25 to 35 per cent to nearly 100 per cent, and thus materially lower the cost of generation, or until some new method of converting the heat energy of coal to electricity is discovered, one of the next steps to lower the cost of production of electricity will be the gas-firing of boilers, the gas being obtained from producers worked at a low temperature. This will provide by-products from the distillation of the coal as a raw material for other industries. The size and position of most of the present power stations prevent this system being used, as by-product processes can only be successfully worked on a large scale and with plant operating at a high load factor; but the increase of electrical energy taken from centralized sources of supply, and the gradual change from comparatively small stations to main power stations, will allow of this method of generation.

(2) *Extension of lighting.*—Apart from hygienic reasons, it is certain that electricity will prevail more and more as an illuminant owing to the greater number of candle-power-hours that can be obtained from a ton of coal by using electricity as compared with gas. With electricity generated in modern power-houses using 25 B.Th.U. per watt-hour, and with 85 per cent efficiency of distribution, the number of candle-power-hours obtained per ton of coal is, with metal-filament lamps of 15 to 20 candle-power, no less than 750,000, as compared with 260,000 in the case of gas, gas mantles of 20 candle-power and 13,000 cubic feet of gas per ton of coal carbonized being assumed. The amount of coal required with electricity for small units of light is thus only one-third of that necessary for an equal illumination with gas.

It may be suggested that further improvements in the gas mantle will equalize matters; but it must be remembered that electricity is more than holding its own in new developments. The half-watt lamps now on sale have again reduced the energy per candle-power-hour by more than 50 per cent for lamps of 120 candle-power (smaller units of light being available when lower pressures than 100 volts can be obtained by transformation).

(3) *Increased range of transmission.*—Further research should result in improved dielectrics which would allow higher working pressures for underground cables, thus lowering the cost of transmission, increasing the size of each centralized undertaking, and again raising the operating load factor by the greater diversity in the demand.

Pending this development, the economical radius of transmission can be increased by using overhead lines outside the thickly populated districts, and it is not too much to expect legislative action in the national, as against private, interests. Statutory powers should allow the erection of transmission lines along the most economical

routes, reasonable rents for wayleaves being fixed by an independent tribunal.

(4) *Domestic uses.*—There is no section of the general supply that opens up greater possibilities than electric cooking and heating, since at a low estimate the units required for these purposes would be 10 times those required for lighting. This development would utilize to much greater advantage the distributing mains in residential areas, which are at present only fully loaded during a few hours per annum.

While the efficiency of conversion in the present electrical apparatus is high, and the system is an ideal one hygienically since there are no products of combustion, development has been slow for the following reasons:—

(1) With the present method of conversion of the heat energy in the coal to electricity it is only possible to deliver to consumers some 15 per cent of the heat energy in the coal. At first sight this low efficiency would appear to prevent any extensive use of electricity for these purposes,

but regard must be had to the low efficiency when coal or gas is burnt direct, owing to the necessity of getting rid of the products of combustion. This low efficiency allows electricity to compete successfully for all intermittent uses, but no large economy of coal can be secured until the present methods of generating electricity are improved.

(2) The present cost of the apparatus and its maintenance. A large expansion of business would enable manufacturers to meet these points, and immediate improvement will take place as soon as the supply undertakings are prepared to let on hire and maintain apparatus on liberal terms in the same manner as the electric motive-power business was developed.

(3) The rates charged for this class of supply are in many cases not sufficiently low to encourage development. A low rate is essential and is justified by the high diversity factor and the large number of hours of use, resulting in a greatly improved load factor from the residential demand.

## HONG-KONG LOCAL SECTION CHAIRMAN'S ADDRESS.

By W. L. CARTER, Member.

(Address delivered 27 May, 1915.)

I propose to take as the subject of this Address the relations subsisting in Europe and America between the public and the public service corporations, and to consider the lessons that may be drawn therefrom for our guidance in the new field that will presently be opened for us in China. If I happen to touch upon matters which arouse strong feeling where home institutions are concerned, it must be remembered that my object is a full and frank discussion of the future of our industry in the vast field of China. I think it is an accepted fact that foreign capital must necessarily be employed for the exploitation of the electrical or any other industry on a large scale, and yet such capital will certainly be withheld until it is adequately protected from the ignorance of the people and the time-honoured cupidity of the official classes. On the other hand, the people of China although guided by a more or less blind instinct are wise in their objection to allowing great financial interests to grow up beyond their control. It is becoming increasingly difficult to draw any hard-and-fast line between public service and private enterprise, and this is primarily due to the organization of labour. Any trade dispute is now liable to throw out of employment large masses of the population and, as it is intended it should, to strike heavily the long-suffering consumer. The organization and conduct of enterprises which were formerly regarded as purely private ventures are fast becoming matters of national importance. There is a large school of thought both in England and America which is in favour of the State acquisition of railways and mines, and curiously enough the people of China, rather than the Central Government, show a strong inclination to retain the railways and mines in the hands of the Pro-

vincial Governments, even at the cost of all immediate prospect of development.

If I turn now to the consideration of public services proper we must keep in view those industries that are becoming of national interest and which, in a new field such as China, may be considered as public services from the outset.

If the history of the recognized public services be examined it is found that private enterprise has almost invariably preceded that of the State or Municipality, and that even such services as roadmaking, disposal of sewage, and water supply have only been taken out of private hands in a tardy and partial manner. It is now generally recognized that such undertakings as these should be carried on by the State, because under existing circumstances it is very difficult for private enterprise to obtain the necessary funds; but should such conditions prevail that the State should be in a similar or even greater difficulty in this respect, and provided that satisfactory conditions can be established between the public and the corporation, there is no valid reason why even these services should not be left to private enterprise.

Such services as these and the supply of electricity and gas, the telephone and telegraph service, and even railway and tramway undertakings, are styled in America "public utilities," or even more concisely "utilities," and it will be convenient to use this brief and expressive Americanism.

From a purely engineering point of view it is unnecessary to elaborate the statement that utilities such as I have mentioned should not be carried on by more than one authority in any one district; and it is due to the fact that in America this has been more generally accepted

than in England, that the utilities of that country have reached a higher level as regards efficiency than is the case with us. The English plan for curbing the obvious evils that are inherent in uncontrolled monopolies has been the introduction of competition, and this has been carried to such an extent that the very word "monopoly" seems a thing of evil. Enterprise and efficiency are undoubtedly throttled by this system, and although the service rendered may be apparently cheaper it is correspondingly inferior.

In the case of railways and tramways serving the same districts a period of cut-throat competition is speedily followed by working agreements which, whilst doing away with the illusory benefits of competition, retain most of the evils of uneconomical operation and inflated capital charges.

Electricity-supply undertakings have generally been allotted their districts, and in the case of municipalities real monopolies exist. The tendency in this branch of engineering is all in the direction of the economies that can be obtained by large undertakings. The immediate future calls for large power stations conveniently situated in respect of fuel, water, etc., and carrying the whole load, including railways and tramways, over considerable areas. The realization of this has been brought home to America and Germany rather sooner than to Great Britain by their natural resources of water power, but very large steam-operated supply systems are now coming into operation in America. The Central Illinois Public Service Company are serving a district of something like 350 miles in radius, and the Public Service Corporation of Northern Illinois have 46,000 consumers in no less than 150 communities, and a load factor of 70 per cent. The Commonwealth Edison Company of Chicago have a maximum load of 230,000 kilowatts, and the full development of the traction load in Chicago has reduced the capital cost per kilowatt to £60, as against the London figure of £80.

London, which should be an ideal electricity-supply area, has no less than 64 generating stations, the output of which has been estimated at one-third of the country's total supply; and although a real effort is being made to untangle the situation, it is one of extraordinary difficulty. Whilst Parliament gave the London County Council the right of purchase in 1931 (by the Act of 1888), unlike the Tramway Act of 1870 the terms of purchase were not settled, and in addition the Council have no power to purchase the numerous municipal undertakings. As the year 1931 draws nearer, this right of purchase with all its uncertainties will have an increasingly malign effect upon the industry and the public. The great railway companies running out of London who are now actively engaged in electrifying their suburban services, seeing no immediate prospect of a satisfactory bulk supply are building their own generating stations; and of the London and South-Western, London and North-Western, Great Northern, Great Western, and London, Brighton, and South Coast Railways only the last-mentioned has arranged for a bulk supply.

The London County Council had intended to introduce a Bill during this session for the gradual absorption of all the London undertakings, but owing to opposition from the various Borough Councils the necessary majority could not be obtained. A Bill has now been introduced to authorize amalgamation of ten of the London supply

companies with an aggregate capital of £6,000,000, but two or three important companies are not included, and as the Bill must be regarded as contentious business there is very little prospect of it being passed in these troubled times. The most interesting point about this Bill, at any rate for the purpose of this Address, is the recognition by the promoters that it is necessary to give the Board of Trade extensive powers, amounting to almost complete control.

In the north-eastern coast districts of England, power companies operating over large districts have come into being, and, in spite of many illogical statutory difficulties in their way, their future is assured. Unfortunately, Parliament has seen fit to exclude these power companies from operating in the large cities in their areas, but this may be a blessing in disguise if it tends to spread the population. New industries are coming into existence as a direct consequence of this cheap power supply.

With the exception of the United States of America all the great States have assumed complete control of their internal telegraph systems, and they are one and all unremunerative. In America the telegraph companies' "stocks" are quite sound, and they are in much the same position as the great railroad companies. It is interesting to note that in the report now before Congress, in which the Federal Postmaster recommends the acquisition of the telephone undertakings by the Federal Post Office, it is proposed to leave the much smaller business of the telegraphs in private hands.

In the case of the telephone, local competition between two administrations is obviously inadmissible. One has only to recall the experience of Glasgow during the short period when its business community had to have two telephone instruments and two directories upon their desks. Stockholm and Los Angeles are in this position, but I am unaware if the inhabitants of these two cities derive any commensurate gratification from being held up as the best-telephoned areas in the world.

Whilst the ideal is an homogeneous system national in extent, the future development in sight is so large that it is very doubtful whether one administration in each State can possibly cope with it. The practical insolvency of the State systems of Great Britain and the Continent is not encouraging.

If then we admit that "utilities" should be allotted their areas within which they will not be subject to direct competition, it is pertinent to ask why, being obviously "everybody's business" they should not be recognized as functions of the Government. That the evils appertaining to uncontrolled monopoly in any field of enterprise are very real will not be denied, and they are most glaringly evident when State or municipal monopolies have been set up, and where public utility corporations have been able to obtain a free hand they have generally ignored the fact that their right to carry on their undertakings is a public grant. Any franchise for the conduct of a utility is really a delegation by Government of certain of its duties, and in this sense the servants including the directors of a utility are public servants and as such exceedingly liable to the attack of the complaint known as "the dead hand of the State."

The efficiency of municipalities and State Governments in the building and maintenance of roads, water, and drainage systems, in the improvement of harbours, and

the organization of their police and naval and military establishments is of a very high order, at any rate as far as Northern Europe is concerned. When we turn to service of a commercial nature, however, although a number of Local Government Councils having business men amongst them have admittedly done well, as a rule such ventures are neither as efficient as they should be nor in a commercially sound position. The chief reason for this is that politics enter into their conduct with a universally baneful effect.

Secondly I place the curious effect which service under Government has upon human nature. Within a few weeks or even days of the transfer of the National Telephone Company's undertaking to the State there arose a wide outcry at the deterioration of the service, and even those who had been foremost in urging the taking over of the service were compelled to add their voices to the general plaint. The Postmaster-General and his officers at first smiled, but when they found that the public were in earnest they pathetically asked if it were to be seriously supposed that some thousands of men and women who awoke upon the morning of the 1st January, 1912, to find themselves civil servants should be less efficient in performing their various duties than they were the day before. I have been assured by those who knew the inner working of the company's system that this is the only possible explanation of what occurred.

A third and powerful influence, as far as national services are concerned, is that Government accounts are really only cash accounts which do not pretend to show more than how money voted has been spent. Commercial accounts are non-existent, or, in a few instances where they have been attempted, very imperfect. The difficulties of conducting an undertaking such as the British Post Office on these lines was well brought out in a paper\* recently read by Sir Charles King, C.B., Comptroller and Accountant-General, before the Telegraph and Telephone Society of London. He points out that the Post Office balance-sheet for the last year, as submitted to Parliament, showed on the revenue side simply three totals:—

Postal service ... ..	£21,750,000
Telegraph service ... ..	3,100,000
Telephone service ... ..	6,900,000

and upon the expenditure side one grand total of £26,227,000; the difference indicating a net revenue of about 5½ millions. These figures give no indication as to what proportion of the net revenue accrues from each of the three services and make no reference to large sums expended by other Government departments for work done for the Post Office. What is still more misleading, no allowance is made in respect of capital charges. The treatment of capital is the most serious default in Government accounting, and yet, as Sir Charles King points out, the preservation of the capital entrusted to them is the primary duty of the directors of a company.

The postal service does not require any considerable capital expenditure; land and buildings, being the only considerable item up to the present, are met out of the revenue. The Post Office tube railway under London will of course require special provision.

\* "Telegraph and Telephone Commercial Accounts," *Telegraph and Telephone Journal*, vol. 1, p. 64, 1915.

Turning to the telegraph service, the valuation of the plant by the Engineer-in-Chief in 1911-12 showed the huge loss of about 21½ millions sterling. This was shown in the balance-sheet dated 31 March, 1912, and with the sanction of Parliament was not carried forward as a debit to the ensuing year. Having passed through bankruptcy in this magnificent manner we might have reasonably expected a more satisfactory result in the future, but the accounts for the year 1913-14 show a net loss on the telegraphs of £1,231,000, and no real effort is apparent to improve this state of affairs. The substitution of the telephone for the suburban and village telegraph operator and her instruments is proceeding and should be pushed, but a more important reform would appear to be the raising of the rates for Press telegrams to a reasonable figure. The total receipts for Press telegrams for last year were only £140,619, and it is quite evident the Government subsidize the Press to no mean extent.

The business of the National Telephone Company was transferred to the Post Office at the end of the year 1911, and for that year the royalty payable by the company to the Post Office, which was 10 per cent of the gross receipts, amounted to £353,700. The company's position was so sound that for some years before the transfer the dividend upon the ordinary shares was 6 per cent. The capital was £15,300,000. The Post Office have regarded this royalty as revenue earned by their competing undertaking, and were thus enabled to show a surplus of £37,119 for the year 1911-12. It would have been reasonable to suppose that the accounts for the year 1912-13 for the combined undertakings would show a profit of at least £750,000. It was actually £303,343, and in 1913-14 it fell by £30,700 to £272,643. The gross revenue for 1913-14 showed an increase of £320,000 over that for the previous year, but so also did the operating expenses. Administration and operating wages increased by 11 per cent, engineering staff by 9 per cent, and engineering supervision by no less than 25 per cent. The last item may possibly be only temporary, but even so it is evident that this huge business must become an increasing burden to the State unless the rates are considerably increased, and I need hardly mention that the public are anticipating anything but that.

In case it should be argued that this state of affairs is a legacy left to the Post Office by the mismanagement of their predecessors, the following figures in reference to the telephone trunk-line service are illuminating. The trunk lines have been the property of the Post Office since 1896. The average charge made per telephone trunk call was 63d. for the years 1912-13 and 1913-14, but the cost per call which in 1912-13 was 64d. increased in 1913-14 to 72d., an increase of 12½ per cent. We might hope that this was due to some temporary condition or that the officers of the Post Office would be spurred to some drastic reforms, but in an Editorial in their "Official Journal" we read: "In view of these figures it is difficult to see how the trunk system is to be made self supporting."

In the United States the Federal Post Office has so far confined its activities to the carriage of mails, and although it has a turnover of £45,000,000 it is in the unique position of conducting the business at a loss. Under these circumstances and in view of the fact that all other large States, including the British Dominions, conduct their telephone

and telephone businesses at a loss, Americans are seriously alarmed at the proposal that their Post Office should acquire the telephones, valued at £220,000,000.

I shall now turn to this question of regulation or control.

Boards such as the Port of London Authority, or the London Water Board, may be set up, purchasing the utilities by the simple process of the issue of new "stock," but if these Boards are to be really representative of all interests they become hopelessly unwieldy, and as has been found in the case of the Water Board, it is more powerful and more inaccessible than the companies it superseded.

Co-partnership between the utility company and the local government is much more hopeful. In Chicago the Commonwealth Edison Company pay the municipality 3 per cent of the gross receipts, but I am unaware whether any advantage is obtained in return. In Germany the utility is allowed the benefit of the municipal credit, whilst the municipality is represented upon the Board and takes a considerable share of the profits. In the case of the Berlin electricity supply the city receives 10 per cent of the companies' gross income and half the net profit after 6 per cent has been paid on the share capital up to M. 20,000,000, and again half the profit left after paying 4 per cent above that amount. The city is now receiving more than half of the sum distributed as profit. Of course this would be altogether excessive unless the advantage of the city's credit were allowed. Strasburg takes its whole supply from a power company which also serves 70 communes in Alsace-Lorraine, and in 1909 the municipality received in dividends and a percentage of the profits £38,000, of which £21,000 was available for the relief of local taxation. In other cases municipalities can subscribe for ordinary shares up to 50 per cent of the issue, or preferential shares at fixed dividends with a further share in the profits, and in either case are directly represented on the Boards.\*

For all municipal services this is surely the best solution of the problem; and where large power schemes and light railways are concerned, all municipalities and county councils in the area to be served should be permitted to become shareholders in the utility on the easy terms permissible on account of the use made of their credit. They would be fully represented upon the Board, and all the obstruction that such undertakings now meet with would automatically disappear.

\* G. KLINGENBERG, "Electricity Supply of Large Cities," *Journal I.E.E.*, vol. 52, p. 123, 1914.

Unfortunately for China, local government is so much in embryo that their assistance in the money market would be the last thing that a projected utility would wish for. The Chinese official, as we now know him, would surely confound co-partnership, which is really joint ownership by the whole community, with the old-fashioned concession which is really a partnership between the officials and the concessionaire for the exploitation of the public, possibly for their well-being.

In the United States of America the State regulation of utilities has been definitely adopted, and under the control of the Commissions we find not only electricity supply, gas, water, telephones, telegraphs, tramways, and light railways, but also the great trunk railroads. Congress has established the Interstate Commerce Commission as an Appellate Court, and has authorized the State Legislatures to set up State Commissions, and although the whole idea is of recent origin this has already been done by 41 States. These Commissions are given various titles, for instance, the California State Railroad Commission, the Kansas Public Service Commission, the Illinois Public Utilities Commission, or the Public Utilities Commission of Ohio.

The Commissions are appointed to deal with all questions relating to public services, such as the ratification of franchises or concessions, the settlement of disputes between undertakers, the revision of rates, amalgamation into joint schemes, the approval of new issues of share capital, technical regulation and inspection, and not only to regulate but to press forward the development of such services. The magnitude of this work will perhaps be realized when I mention that the Public Utilities Commission of Ohio has been instructed by the State Legislature to prepare a valuation or appraisal of the 1,500 utility companies under its control, and that the Illinois Public Utilities Commission handed down in one year 800 judicial decisions. Men of high standing are appointed with very ample powers and so far there has been no adverse criticism.

I feel that China should follow upon this lead by the appointment of Commissioners for each Province of the Empire, not necessarily appointed at one time, but as the demand arises. They should have wide judicial powers, and, as long as extra-territoriality exists, should be of mixed nationality. There would be an appeal to a Central Trade Commission or Board of Trade upon which foreign financial interests would have to be sufficiently represented. Until the Chinese can be made to see the necessity for this no real progress is possible.

## A NEW HIGH-EFFICIENCY INCANDESCENT LAMP.

By E. A. GIMINGHAM, Member, and S. R. MULLARD, Associate Member.

*(Paper first received 16 September, and in final form 4 October, 1915.)*

It is now more than 100 years since the first arc lamps were experimented with, 39 years since the introduction of the Jablochhoff candle, and 34 years since the first incandescent lamps with carbon filaments were brought into commercial use.

During the past 13 years metal-filament lamps have been slowly displacing lamps with carbon filaments, with the result that the tungsten-wire lamp now holds the leading position for lighting.

In 1913, experiments were started in the lamp research laboratory of the Edison & Swan United Electric Light Company at their Ponders End works, with the object of making a lamp having the usual characteristics of the ordinary incandescent lamp, that is to say as regards the shape and size of bulb, stem, and cap, but having as the source of light an arc having electrodes of tungsten or other suitable refractory conductor burning in an inert gas such as nitrogen or argon.

The present paper describes the results of this work.

## CONSTRUCTION OF THE LAMP.

The first lamps constructed were made with the electrodes in contact, one of the electrodes being connected to an expansion strip constructed of a strip of molybdenum, to one side of which was welded a thin strip of copper or other suitable material having about the same coefficient of expansion. A spiral filament of tungsten or molybdenum was mounted close to the strip and wired in series with the arc circuit. To prevent the strip moving too far and the arc breaking, a thick wire was sealed into the glass support; this wire acted as a stop and maintained the correct length of arc gap.

For alternating-current lamps the electrodes were constructed of fused tungsten and were of equal size.

For use with continuous current, in one form of lamp the positive electrode was constructed of a globe of fused tungsten, while the negative electrode consisted of a number of tungsten wires or filaments mounted in the form of a brush. The whole of the parts were assembled as shown in Fig. 1, and sealed in an ordinary incandescent lamp bulb, which, after being thoroughly exhausted of air, was filled with nitrogen at a pressure of approximately two-thirds of an atmosphere.

When connected to a continuous-current circuit through a suitable resistance the current passing through the coil A produced sufficient heat to cause the expansion strip B to warp, thus separating the electrodes E, E, and striking an arc between them. The temperature of the heating coil then dropped to a very dull-red heat due to the added resistance of the arc itself. The heat from the arc was more than sufficient to keep the expansion strip hard against the stop F, and thus to maintain the requisite length of arc gap.

The arc burned steadily and the electrodes emitted an intense white light. The lamp had, however, many disadvantages, the most important being the tendency of the electrodes to stick together, with the result that the expansion strip failed to separate them slowly. Again, a considerable amount of sputtering took place when the electrodes separated, which in consequence shortened the life of the lamp. However, in the course of development, principally by altering the shape and size of the electrodes, a lamp was evolved from which a life of over 100 hours was obtained. Other attempts to overcome the sticking of

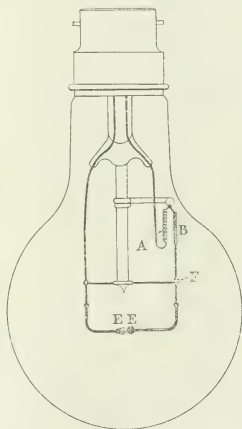


FIG. 1.

the electrodes included altering the physical state of one electrode, also the use of a short-circuiting piece placed between them, which on the current passing was removed. These and other devices did not entirely overcome the troubles of sticking and sputtering.

The whole problem was then tackled from another direction. It was assumed, from the results so far obtained, that if the difficulties of striking could be overcome there were possibilities of obtaining a satisfactory source of light, the whole of the light emanating from a source of very small dimensions.

It is well known from the experiments of Sir J. J. Thomson, Dr. Fleming, and others, that the filament in an incandescent lamp gives off a strong negative discharge, and if an additional electrode sealed adjacent to the filament be charged to a positive potential, a current passes between the filament and this electrode.

An application of this principle was applied to overcome the difficulties encountered in making an arc incandescent lamp.

The first attempts on these lines were made with a lamp suitable for an alternating-current circuit. This lamp consisted of two small globules of tungsten fixed at a definite distance apart. As a means of breaking down the resistance of the gas within the arc gap, a filament was mounted adjacent to the electrode; this filament, when made to glow brightly for a few seconds, acted as an ionizing agent and made the arc gap conducting.

As used in the lamp, this ionizing circuit was connected in parallel with the arc circuit through an auxiliary single-pole switch and suitable resistance. On starting, the ionizing circuit was completed for a few seconds and then broken by means of the switch. This resulted in an arc being momentarily struck between one of the electrodes and the filament, this being followed by an arc between both electrodes, the filament acting as the ionizer being now entirely out of the circuit.

This lamp showed great improvement as regards both facility in striking and life.

Efforts were then directed to make a lamp for continuous-current circuits. At the start, the construction of this lamp was similar to that used for alternating current, with the exception that the negative electrode was smaller. To start the lamp the filament acting as the ionizer was brought to high incandescence and then cut out by means of a switch in the positive lead. Difficulties were experienced in inducing the arc to leave the tungsten-filament ionizer and pass to the negative electrode. This trouble was due to the difficulty of bringing the negative electrode to a temperature high enough to form an arc. In the alternating-current arc the electrode which momentarily formed the arc with the ionizer helped to form the arc proper, but with the continuous-current lamp the arc persisted in passing between the positive electrode and the ionizer.

Later on, negative electrodes were made, to which in the majority of lamps the arc would strike, but it was felt necessary to provide thoroughly for the protection of the ionizer. This was desirable, inasmuch as the prolonged action of the arc tended to damage the ionizer, which after a time added to the difficulty of striking.

To try and obtain an ionizer which had a longer life than the previously used tungsten filament and which retained its activity throughout the life of the lamp, a study was made of the action of other materials than tungsten for use as an ionizer. It is well known that several refractory oxides possess to a very high degree the property of emitting electrons; experiments were therefore made with mixtures and combinations of tungsten with zirconia, yttria, thorium, and other oxides of the refractory class.

As a result of continued experiments, a satisfactory filament giving powerful ionization properties was evolved, it being found that if the filaments were carefully made they were not destroyed by the action of the arc and that they

lasted considerably longer than a filament of pure tungsten, this being no doubt due to the difference in the physical state of the two filaments. However, difficulties still remained in the matter of restarting. The action of the arc after a time naturally destroyed the ionizing properties of the filament, and in some cases difficulty was experienced in restriking after 200 hours' burning. This deterioration of the ionizing properties of the filament was only local, being merely around a short length directly opposite the anode.

To overcome this objection, a short length of expansion strip similar to that used in Fig. 1 was linked between the anode and its stem lead. A lamp constructed in this

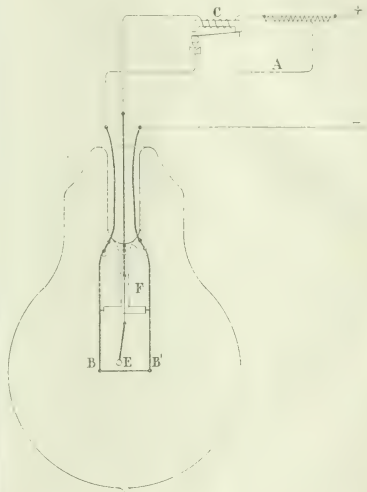


FIG. 2.

manner is connected as shown in Fig. 2, which illustrates a lamp suitable for a continuous-current circuit. Three leads are necessary through the lamp stem; on one is mounted the electrode E, while the other two hold the filament, acting as an ionizer, B B'. The positive main lead is divided into two circuits, one of which, A, passes through a resistance and the contacts on the electromagnetic switch C to one pole of the ionizer B, the other being taken through a resistance and the coil on the electromagnetic switch to the positive electrode of the arc circuit E. The negative main lead is connected to the remaining ionizer lead B'.

In operation the current first passes through the ionizer circuit, causing the filament to incandesce at a temperature sufficient to ionize the gas between it and the positive electrode. At first a small current flows in the arc circuit,

this current rapidly increasing until the cut-out is operated. This breaks the ionizer circuit and the arc is "struck," the striking being assisted by the removal of the ionizer circuit, which of course shunted the arc circuit. The heat rising from the arc causes the expansion strip F to warp, and this moves the arc to another position on the ionizer.

On switching off the current the electrode returns to its original position, having left the inactive part and coming to rest opposite the still active portion of the ionizer. By this means the lamp may be restarted at any period of its life without difficulty.

In this lamp practically the whole of the intense white light emanates from a small globule of fused tungsten 1/10 inch in diameter.

Any size or shape of electrode may be made, the construction of the higher candle-power lamps being arranged as shown in Fig. 3. Here the expansion strip is dispensed

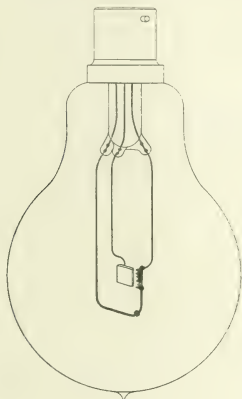


FIG. 3.

with, use being made of the fact that in the more powerful arcs there is a greater tendency for the arc to pass across the shortest gap. In this case, after striking from the filament to the edge of the electrode, the arc rises to the thickened portion immediately opposite.

Another method adopted for controlling the arc stream in lamps of high candle-power is to employ an extra lead through the stem, holding a smaller electrode fixed between the positive plate and the filament, and situated at a definite distance from the former. By the operation of change-over switches in the circuit an arc is first struck between the filament as cathode and the small electrode as anode. On this electrode becoming brightly incandescent the change-over switch quickly operated brings into the circuit the large plate electrode, at the same time breaking the negative connection to the filament and changing the polarity of the small white-hot electrode. This latter now

being negative, an arc is immediately formed between it and the large positive plate. This arrangement enables electrodes of any size to be used, and the filament being out of the circuit is completely protected.

A flat electrode is also employed. To obtain the best results a definite relation of surface to volume must be maintained. This type of lamp is made in sizes of 500 to 1,000 candle-power, the maximum intensity being given in a direction at right angles to the plane of the electrode.

#### COMPARISON WITH ARC AND INCANDESCENT LAMPS.

As compared with the carbon arc lamp no regulating mechanism is required, and there is therefore a saving in the initial cost of production. The loss of light due to obstruction by the electrodes is small compared with that in the carbon arc, and there is no trouble from flickering or from the arc wandering. The arc is completely enclosed so that there is no danger from fire. No re-carboning is required, and the lamp needs no attention whilst in use. The light-giving surface for the same output is greater than the crater of the carbon arc, and the electrodes can be so arranged as to concentrate the light in any desired direction.

Filaments of incandescent lamps are always distributed round the stem and thus occupy a fairly large area, whereas in the new lamp the light-giving surfaces are concentrated in the centre of the bulb. In the same way that a carbon lamp appears yellow in comparison with the ordinary half-watt lamp, so does the latter appear yellow when contrasted with the new incandescent arc. For high candle-power lamps the bulbs are much smaller than for metal-filament lamps of corresponding candle-power, e.g. electrodes to give 500 candle-power can be placed with safety in a bulb 4 inches in diameter.

#### CHARACTERISTICS OF LAMP, ETC.

Curve A (Fig. 4) shows the percentage variation of pressure with current. As will be seen, the curve is

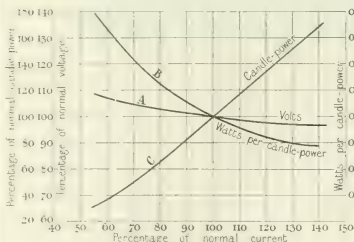


FIG. 4.

similar to that for an ordinary carbon arc, though showing greater stability. The pressure across the arc steadily decreases with an increase of current, and if continued until the sputtering point is reached, the pressure suddenly drops.

A representative efficiency curve is given by B in Fig. 4, which shows the efficiency for the normal working current to be about 0.5 watt per International candle-power, or 2 candle-power per watt. The current may be increased until the tungsten reaches the sputtering point, at which the efficiency is about 0.3 watt per candle-power or 3.33 candle-power per watt.

Curve C in Fig. 4 shows the variation of candle-power with current.

#### RUNNING TESTS, LIFE OF LAMP, ETC.

Lamps have been made with a life of 500 hours, and it is hoped that further experiment will make it possible to obtain a true half-watt lamp with a life of 800 hours. During life the average decrease in candle-power is about 10 per cent.

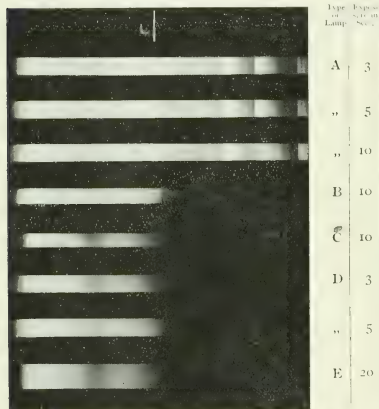


FIG. 5.  
A = Incandescent  
B = 1/2 watt wire  
C = 1/2 watt wire  
D = Nernst filament  
E = Acetylene

Some experiments to determine the effect of varying the pressure across the supply mains showed the arc to be very stable. A voltage drop of 20 per cent in the case of the small lamps, and 25 per cent in the larger sizes, was necessary before the arc was extinguished.

#### INTRINSIC BRILLIANCY.

As compared with the carbon-filament lamp (3.5 watts per candle-power) with an intrinsic brilliancy of about 375 candle-power per square inch, and metal-filament lamps giving 1,000 candle-power per square inch, the intrinsic brilliancy of the new lamp at an efficiency of 0.5 watt per candle-power, or 2 candle-power per watt, is approximately 10,000 candle-power per square inch. The colour of the light can be made to vary from a bright

yellow when running at low efficiencies, to a very intense white light when the lamp is run to the sputtering point of the electrodes. The range of intrinsic brilliancy between these limits is approximately 400 to 30,000 candle-power per square inch.

#### SPECTRUM ANALYSIS OF LIGHT EMITTED.

Interesting photographs of the spectra of various lamps are illustrated in Fig. 5. In this figure, A is reproduced from photographs of the spectrum of the new lamp, D from those of a Nernst filament, while C and B show those of the 1/2-watt drawn-wire lamp and the half-watt gas-filled drawn-wire lamp respectively. As the acetylene lamp is sometimes used for the purpose of colour-matching, a spectrogram of this lamp is shown at E. In each case the visible spectrum extends from the left of the photograph (the red) to the letter L (the limit of the violet).

Comparisons of the above spectra clearly show the continuity and strength in the visible spectrum of the new lamp, the other sources of light showing weakness in the green and at other points.

#### LIGHT DISTRIBUTION.

A great advantage of a lamp of this time is its adaptability (by altering the shape and position of the electrodes) in so varying the light distribution as to make it most suitable for the particular purpose for which the lamp is required. Where even illumination is required in all directions, spherical electrodes are most suitable. Electrodes can be made of any desired shape, however, and a flat plate or disc mounted vertically is an ideal light source for projection purposes.

#### SUGGESTED USES OF THE LAMP.

The lamp is made for both alternating and continuous-current circuits, and the present intention of the Edison & Swan Company is to put forward only the continuous-current lamp in its present form for optical projection and general scientific work where a concentrated point source of light is required. The lamp is so suitable for projection work that there is every reason to believe it will supersede all other sources of light for this purpose. It gives constant, uniform screen illumination, whilst there is no flickering and no danger of fire in cinematograph work as there often is from the intense heat of the ordinary carbon arc. The bulb of the lamp, although smaller, does not become so hot as those of the half-watt metal-filament lamps. Moreover, the lamp requires no attention whilst burning, so that the whole of the operator's time is free to attend to his apparatus. Lamps of 1,000 to 2,000 candle-power are suggested as very suitable for cinematograph projection, and lamps of 200 to 300 candle-power for ordinary lantern work.

The lamp is very suitable for use in small searchlights, for daylight and night signalling, and as projection arcs for stage purposes. It should prove useful in photography, and for the purpose of colour-matching by artificial light. Micro-scope illumination and micro-photographic work offer two fields of usefulness for the new lamp, and undoubtedly there are many special purposes for which the lamp is particularly adapted.

Experiments have shown that the lamp burns satisfactorily in series on high-voltage circuits, and future development lies in the adaptation of the lamp for street lighting, and for the illumination of large halls, etc.

Although much work remains to be done for the com-

plete development of the lamp, and such development takes place slowly in these troublous times, the laboratory tests have clearly shown its commercial possibilities.

The authors are indebted to Dr. J. Fox for his valuable help in providing the photographs of the various spectra.

## THE AMPLITUDE AND PHASE OF THE HIGHER HARMONICS IN OSCILLOGRAMS.

By Professor G. W. O. HOWE, D.Sc., Member.

(Paper received 11 August, 1915.)

It is well known that the formulæ representing the oscillations of mechanical and electrical systems are similar, and that results obtained for electrical cases are directly applicable to the analogous mechanical cases. Mass in the mechanical system is equivalent to inductance in the electrical, displacement per unit force to capacity, applied force to applied electromotive force, damping resistance to electrical resistance, and displacement or amplitude to electrical displacement or quantity. The equivalence of motional resistance and electrical resistance is often only approximate, since the former may not be constant but may vary with the velocity.

The mechanical system which we are here considering consists of the strips and mirror of a Duddell oscillograph; by immersing these in oil, we not only increase the damping but also the effective mass of the moving parts, since the strips cannot move without carrying with them some of the oil. This increase of the effective mass causes the resonant frequency of the system when placed in oil to be lower than it would be in air.

As a rule, an electrical engineer is more familiar with the numerical and graphical consideration of alternating currents than with the calculation of mechanical oscillations, and in this communication it will be shown how the simple vector diagrams of an electric circuit may be employed to throw light on the mechanical oscillations of the strips of an oscillograph.

The question which led to this investigation was the doubt as to the accuracy of the magnitude and phase of the ripples in the potential-difference wave of alternators as recorded by the oscillograph. The author has recently shown\* that the ripples due to the teeth of an alternator should be symmetrical with respect to the fundamental, assuming that the machine is on open circuit and that there is no dissymmetry in the magnetic field. Many oscillograms showed the ripples to be unsymmetrical, and the question arose as to whether the oscillograph could be in any way to blame. We may anticipate by saying that the oscillograph was completely exonerated and that the cause of the displacement of the ripples must be sought elsewhere.

In an electric circuit containing an inductance  $L$ , a condenser of capacity  $C$ , and a resistance  $R$ , let an alter-

nating electromotive force  $E$  with a frequency  $f$  be introduced, producing a current  $I$ . The potential difference across the resistance is  $IR$ , that across the inductance (assumed to have no resistance) is  $I\omega L$ , and that across the condenser  $I/(\omega C)$ , where  $\omega = 2\pi f$  and  $E$  and  $I$  are root-mean-square values. If  $f$  be adjusted until resonance is obtained, *i.e.* until the current is a maximum,  $I\omega_0 L = 1/(\omega_0 C)$ , or  $\omega_0 = 1/\sqrt{LC}$  and  $I = E/R$ , as shown in Fig. 1.

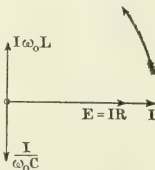


FIG. 1.

The displacement or quantity in the condenser is in phase with the potential difference across the condenser and is therefore  $90^\circ$  behind the applied electromotive force  $E$ . Turning for a moment to the mechanical case of the oscillograph strips, it is obvious that the applied mechanical force is proportional to, and in phase with, the current passing through the strips. Hence, for any current having the resonant frequency, the oscillograph would give a phase displacement of  $90^\circ$  between the current through it and its indications.

The maximum displacement or amplitude is

$$Q_{\max.} = \frac{I_{\max.}}{\omega_0} = \frac{E_{\max.}}{\omega_0 R},$$

whereas a steadily applied electromotive force of the value  $E_{\max.}$  would give a quantity, displacement, or amplitude of  $E_{\max.} C$ . Hence, the magnification, *i.e.* the ratio of the displacements obtained with alternating and steadily applied forces respectively of the same instantaneous value, in the case of resonance is equal to  $1/(\omega_0 CR)$  or  $\omega_0 L/R$  or  $\sqrt{L/C R^2}$ .

\* Journal I.E.E., vol. 53, p. 243, 1915.

If we assume that the damping is adjusted until it is critical, *i.e.* until the system is just aperiodic, which is done in the mechanical case of the oscillograph by altering the viscosity of the oil in which the vibrating strips are immersed, and in the electrical case by altering the resistance of the circuit, we have the well-known condition

$$4L = CR.$$

Hence, with critical damping, the magnification at resonance is

$$\sqrt{\frac{L}{CR}} = \sqrt{\frac{1}{4}} = \frac{1}{2}$$

and

$$\frac{\omega L}{R} = \frac{1}{R} (\omega C) = \frac{1}{2}.$$

so that in Fig. 1 the horizontal vector  $IR$  is twice as long as either of the vertical vectors  $I\omega_0 L$  and  $I/(\omega_0 C)$ .

Considering now the more usual case when the applied frequency is less than the resonant frequency, let  $k = \frac{\text{applied frequency}}{\text{resonant frequency}}$ , so that  $\omega = k\omega_0$ .

The steady displacement or quantity is as before  $E_{\max}/C$ , where  $E_{\max}$  is the applied steady electromotive force, but

Since, for critical damping,  $\omega_0 CR = 2$ , the magnification in the above case will be

$$\frac{E}{\omega R} = \frac{2}{k+1} \div E_{\max}/C = \frac{1}{k+1}$$

When  $k=1$ , *i.e.* for resonance, this becomes 0.5, and as  $k$  is decreased the magnification approximates more and more closely to unity. When looking at an oscillogram one usually assumes that the magnification is unity for every harmonic. The angle  $\theta$  in Fig. 2 is the angle by which the condenser potential difference and therefore also the quantity or displacement lags behind the impressed electromotive force;

$$\sin \theta = \frac{IR}{E} = \frac{R}{\sqrt{1 + (1/(2k) - k)^2}} = \frac{2k}{k^2 + 1}.$$

The values of the magnification and of the angle  $\theta$  are given in the table for various values of  $k$ , both smaller and larger than unity.

TABLE I.

Oscillograph with Critical Damping.

$k = \frac{\text{Frequency}}{\text{Resonant frequency}}$	Magnification	Phase Displacement in Degrees
2	0.2	127
1.75	0.246	120.5
1.5	0.308	112.7
1.25	0.39	103
1	0.5	90
0.8	0.61	77
0.5	0.8	53
0.25	0.941	28
0.1	0.99	11.4
0.025	0.9994	2.86
0.01	0.9999	1.15

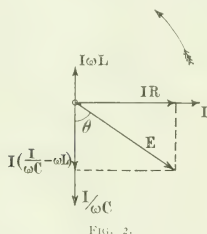


FIG. 2.

for the displacement with alternating currents we have (see Fig. 2)

$$\begin{aligned} Q_{\max} &= \frac{I_{\max}}{\omega} = \frac{1}{\omega} \cdot \frac{E_{\max}}{\sqrt{[R^2 + (\omega L - 1/(\omega C))^2]}} \\ &= \frac{1}{k\omega} \cdot \frac{E_{\max}}{\sqrt{[R^2 + (kR/2 - 1/k \cdot R/2)^2]}} \\ &= \frac{E_{\max}}{\omega R} \cdot \frac{2}{k+1} \end{aligned}$$

We have assumed critical damping, for which we found that  $\omega_0 L = 1/(\omega_0 C) = R/2$ , where  $\omega_0$  is  $2\pi$  times the resonant frequency. It is necessary to distinguish carefully between the resonant frequency and the natural frequency with which the system would oscillate if the applied force were suddenly removed. The latter is less than the former owing to damping; and although for a small amount of damping the difference between them is small, they differ widely as the damping approaches the critical value. For critical damping the system ceases to have any natural frequency, since it is aperiodic, but it still has a resonant frequency which is unaffected by variations of the damping. At the resonant frequency a given applied force produces a maximum current, or rate of change of displacement.

Now in a 3-phase generator with 3 slots per pole and phase, we are interested in the 17th and 19th harmonics, and if the fundamental frequency be 50, that of the 19th harmonic will be 950. A Duddell projection oscillograph in oil has a resonant frequency of about double this value, so that  $k$  is about 0.5, for which the table gives a phase displacement of 53°. At first sight, one might be led to think that he had discovered here the cause of the displacement of the tooth ripples, but it is a false clue, since 53° in the 19th harmonic is only equivalent to 2.8 degrees in the fundamental. Now the fundamental has a frequency of 50, giving for the value of  $k$  about 1/40, for which the table shows a displacement of 2.9 degrees. Hence the whole curve, fundamental and harmonics alike, is displaced uniformly about 3° with practically no distortion. With twice this number of slots, however, the same machine would give tooth ripples very near the resonant frequency, but even then the phase distortion is small, as may be seen by considering the 40th harmonic and assuming that it is exactly of the resonant frequency. The phase displacement of the fundamental, for which  $k$  would be 1/40, is exactly 2.864 degrees, which measured on the scale of the 40th harmonic is equivalent to  $2.864 \times 40 = 114.56$  degrees. Now the resonant 40th harmonic will only be displaced

90°, so that it will appear to lead or to be shifted to the left 24.5 degrees of the harmonic; even in the extreme case of the harmonic being in resonance with the oscillograph, the displacement is therefore very small, and is in the opposite direction to what one might expect. Its amplitude would be reduced, however, to half its proper value, whereas in the previous case, in which the frequency of the harmonic was about 50 per cent of the resonant frequency, the amplitude was reduced to 0.8 of its proper value.

From Figs. 3, 4, and 5\* in which the values given in the table are plotted, it will be seen that with critical damping there is nothing striking either in the amplitude or phase of a harmonic as it passes through the resonant frequency of the oscillograph. For frequencies above resonance the

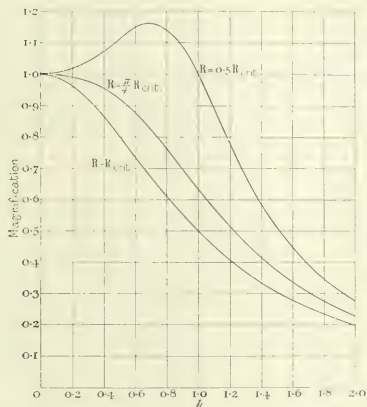


FIG. 3.

amplitude continues to decrease, while the relative phase advancement of the harmonic with respect to the main wave increases very rapidly, as shown in Fig. 5.

*Underdamped oscillograph.*—If, in the electric circuit,  $R$  be decreased, the magnification at resonance will still be

$$\sqrt{\frac{L}{CR}} = \frac{1}{\omega_0 CR} = \frac{1}{R}$$

but this will no longer be 0.5. If  $L$  and  $C$  remain unchanged, the magnification will be inversely proportional to  $R$ ; and if  $R$  be halved, the magnification will become unity, i.e. the maximum amplitude for an alternating force will be equal to the steady deflection produced by a continuous force equal to the maximum alternating

force. This is only at resonance. The phase displacement at resonance is always 90°, irrespective of the damping. If, as we have assumed,  $R$  is made equal to 0.5 of the value required to give critical damping, the vector  $I R$ , instead of being equal to  $2 I \omega_0 L$  or  $2 I / (\omega_0 C)$  as it was in Fig. 1, will now be equal to  $I \omega_0 L$  or  $I / (\omega_0 C)$ ; that is to say, at resonance the potential differences across the inductance, condenser, and resistance will all be equal. If now the frequency be reduced to some value  $k$  of its resonant value, we have

$$Q_{\text{max}} = \frac{I_{\text{max}}}{\omega} = \frac{1}{\omega} \cdot \frac{E_{\text{max}}}{\sqrt{1R + (R/k - Rk)^2}}$$

A continuous electromotive force equal to  $E_{\text{max}}$  would produce a displacement of  $E_{\text{max}} C$ ; hence the magnification is equal to

$$\frac{k}{\omega CR} \cdot \frac{1}{\sqrt{(k^4 - k^2 + 1)}} = \frac{1}{\sqrt{(k^4 - k^2 + 1)}}$$

since  $k/(\omega CR) = 1$ .

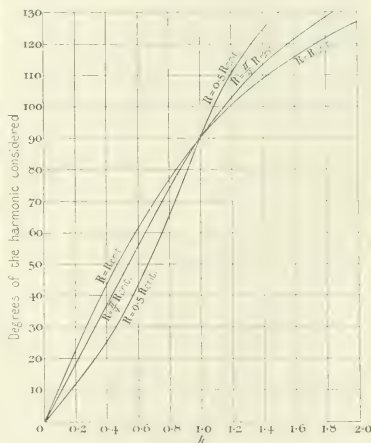


FIG. 4.—Absolute Phase Displacement.

The angle  $\theta$  by which the displacement lags behind the applied force is given by the formula

$$\sin \theta = \frac{I R}{E} = \frac{k}{\sqrt{(k^4 - k^2 + 1)}}$$

or

$$\tan \theta = \frac{1}{1/k - k} = \frac{k}{1 - k^2}$$

The values given by these formulæ are shown in the following table and are plotted in Figs. 3, 4, and 5.

\* Amplitude curves similar to those in Fig. 3 were given by Professor Salomonson in the *Electrician*, vol. 69, p. 357, 1912.  
J. K. A. W. SALOMONSON. "Some Points in the Use and the Theory of the Oscillograph."

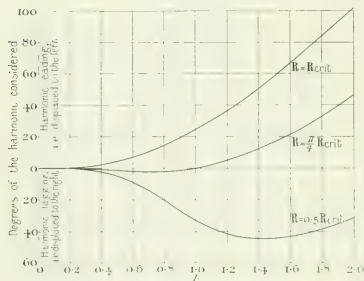
TABLE 2.

*Underdamped Oscillograph.*

(Damping resistance = 0.5 of critical value.)

$k =$ Resonant frequency	Magnification	Phase Displacement in Degrees
2.0	0.277	146.33
1.75	0.371	130.53
1.5	0.512	120.82
1.25	0.729	114.25
1	1.000	90
0.8	1.14	65.8
0.5	1.111	33.7
0.25	1.03	14.92
0.1	1.004	5.76
0.025	1.0003	1.43
0.01	1.00005	0.57

If we assume, as before, that the resonant frequency of the oscillograph strips is 2,000, and that the fundamental frequency of the alternator is 50, then for this fundamental frequency  $k = 0.025$  and  $\theta = 1.43$  degrees. This corresponds to 27.2 degrees of the 19th harmonic, for which  $k = 0.475$  and  $\theta = 31.75$  degrees. Hence the apparent displacement of this harmonic is only 4.5 degrees of the harmonic, or 0.24 degree of the fundamental. In this case, the harmonic appears to lag, whereas with critical damping it appeared to lead. The apparent lag of the harmonics for

FIG. 5.—Relative Phase Displacement, assuming  $k = 1/40$  for the Fundamental.

values of  $k$  between 0 and 2 is plotted in Fig. 5. The fact that decreasing the damping to a half of the critical value caused the apparent displacement of the harmonic to change from leading to lagging, indicates that for some intermediate value of the damping the apparent displacement of the harmonics would be reduced to a very small value, so that they would retain their positions relatively to the fundamental and thus cause minimum distortion, so far as phase is concerned. It can be easily shown that the relative phase displacement of the resonant harmonic is reduced to zero by making the damping resistance  $\pi/4$  of

its critical value. For let  $R$  be  $a$  times the critical value, then

$$R = 2\pi\omega L, \quad L = 2\pi \cdot \frac{1}{\omega C}$$

and we have

$$\tan \theta = \frac{R}{1/\omega C - \omega L} = \frac{R}{R_0(2ak) - kR/(2a)} = \frac{2a}{1/k - k'}$$

If the resonant harmonic be the  $n$ th, its phase displacement will be  $90^\circ$  and the fundamental must be displaced  $90/n$  degrees, i.e.,  $\pi/2n$  radians, to prevent distortion. Hence we must have

$$\tan \frac{\pi}{2n} = \frac{2a}{n - 1/n'}$$

or since  $\pi/(2n)$  is small,

$$\frac{\pi}{2n} = \frac{2a}{n - 1/n'} = \frac{2a}{n} \text{ approximately.}$$

Hence

$$a = \pi/4.$$

On substituting this value of  $a$  in the formula for  $\theta$ , we have

$$\tan \theta = \frac{1.571}{1/k - k} = 1.571 \frac{k}{1 - k^2}$$

The magnification is easily seen to be

$$\frac{1}{\sqrt{(1 + k^2 + 0.47k^2)}}$$

or, in general for any value of  $a$ ,

$$\frac{1}{\sqrt{[1 + k^2 + 2k^2(2a^2 - 1)]}}$$

By putting  $a = 1$ , this gives the result already obtained for critical damping.

Table 3 gives the magnifications and phase displacements for various values of  $k$ , on the assumption that  $R = \pi/4 R_{crit}$ . The results are plotted in Figs. 3, 4, and 5.

TABLE 3.

*Underdamped Oscillograph.*

(Damping resistance = 0.7854 of critical value.)

$k =$ Resonant frequency	Magnification	Phase Displacement in Degrees
2.0	0.23	133.7
1.75	0.291	127
1.5	0.375	117.9
1.25	0.489	106
1.0	0.637	90
0.8	0.704	74
0.5	0.92	46.32
0.25	0.985	22.73
0.1	0.995	9.025
0.025	1.000	2.25
0.01	1.000	0.9

It will be seen from Fig. 5 that the relative displacement is almost negligible for all frequencies up to resonance. This is obviously the ideal value for the

damping if the object be to examine the phase relationship of the harmonics. In Fig. 5 the curves of relative or apparent displacement are plotted on the assumption that the fundamental frequency is a fortieth of the resonant frequency. If  $R = \pi/4 R_{crit}$ , i.e. with the oscillograph

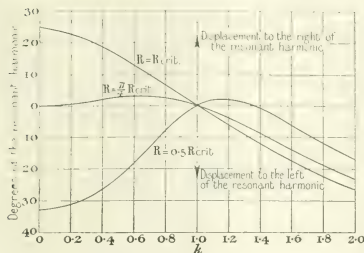


FIG. 6.—Relative Phase Displacement with respect to the Resonant Harmonic, measured in Degrees on the Scale of the Resonant Harmonic.  
Frequency  
 $k = \frac{\text{Resonant frequency}}$

slightly underdamped, no harmonic below resonance is displaced more than  $2^\circ$  of the harmonic. This would be impossible of detection. With critical damping, even at resonance, the displacement is only  $25^\circ$  of the harmonic,

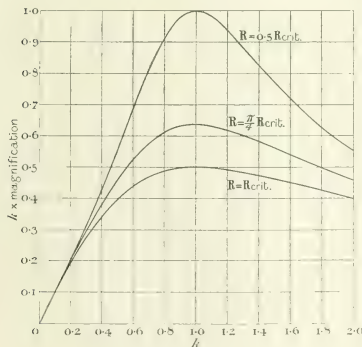


FIG. 7.

which might just be detected with difficulty as a slight dissymmetry in a wave otherwise symmetrical.

For correctness of amplitude it is better to reduce the damping until  $R$  is little more than half of the critical value. With  $R = 0.5 R_{crit}$ , the amplitude is within 17 per

cent of its correct value for all harmonics up to 15 per cent above resonance, while the phase relations are little inferior to those obtained with critical damping. With  $R = 0.6 R_{crit}$ , both amplitude and phase are much more correct than with critical damping.

In Fig. 6 the relative phase displacement is plotted in a way more suitable for general application. Instead of any assumed fundamental, the resonant harmonic itself is taken as the standard of reference, and the ordinates give the relative displacement of a wave of any other frequency, expressed in degrees of the resonant harmonic.

The result of a study of these curves must be to increase one's confidence in the indications of the oscillograph when applied to periodic currents. It can be used for frequencies up to, and beyond, its resonant frequency, if care be taken in interpreting the results. Under these circumstances it is important to know both the resonant frequency and the damping. The magnification curves give no direct indication of the attainment of resonance. In an electric oscillatory circuit resonance is detected by obtaining a maximum reading on the ammeter; similarly here, if one multiplies the amplitude obtained at each frequency by the frequency and thus obtains a figure proportional to the rate of change of displacement, resonance will be indicated by this product reaching a maximum value as shown in Fig. 7; the alternating current through the instrument must, of course, have a constant value for all frequencies. The magnification which is obtained at this resonant frequency indicates at once the value of the damping relatively to the critical value. We have seen that

$$\text{magnification} = \frac{1}{\sqrt{1 + k^4 + 2k^2(a^2 - 1)}};$$

for resonance  $k = 1$  and magnification  $= 1/2a$ .

We have therefore

$a = \frac{R}{R_{crit}}$	Magnification at Resonance
2	0.25
1.5	0.333
1.0	0.5
0.75	0.667
0.6	0.833
0.5	1.000

Knowing the value of  $a$ , the amplitude and phase of the higher harmonics can be corrected if necessary.

It is evident from Figs. 3, 5, and 6 that for frequencies up to 0.2 of the resonant frequency the accurate adjustment or knowledge of the damping is unimportant. It is fortunate that this is so, since the usual method of judging the damping by applying a sudden make and break is not capable of great accuracy. With critical damping, the oscillograph just fails to overshoot when the circuit containing some continuous electromotive force is suddenly closed. If the damping is reduced the oscillation produced on the make has a damping coefficient  $\beta = R/2L$  (using the electrical analogy for the mechanical oscillation), and successive amplitudes in opposite directions have a ratio  $e^{-\beta T/2}$ . Now  $R = a R_{crit}$  and  $R_{crit} = 2\sqrt{L/C}$ , so that

$\beta T = \frac{a}{2f} \sqrt{\frac{1}{1-a^2}} = \pi a / f$ , where  $f$  is the resonant frequency and  $f$  the natural frequency. Since  $f = f_0 \sqrt{1-a^2}$ ,

$$\beta T = \frac{\pi a}{\sqrt{1-a^2}}$$

If  $a = 1$ ,

the logarithmic decrement per half-period  $= \beta T/2 = \infty$

If  $a = \pi/4$ ,

the logarithmic decrement per half-period  $= \beta T/2 = 4$

If  $a = 0.5$ ,

the logarithmic decrement per half-period  $= \beta T/2 = 1.81$

Since  $\epsilon^{-1.81} = 0.183$  and  $\epsilon^{-1.81} = 0.104$ , we see that with  $\pi/4$  of the critical resistance, the first overshoot on make is 1.83 per cent of the steady deflection, which would be

detected with difficulty in most oscillograms, while, if  $a = 0.5$ , the overshoot is increased to 16.4 per cent.

It would appear, therefore, that for general purposes an oscillograph should be adjusted until there is a slight, but obvious, overshoot on suddenly applying a steady potential difference.

In conclusion the author would draw attention to the work of M. André Blondel, who published many contributions on the subject between the years 1891 and 1902. In *L'Eclairage Électrique* for the 28th October of the latter year he gave a very complete mathematical investigation of the theory of the oscillograph. Although the method of investigation was different, the conclusions arrived at by M. Blondel are, in general, the same as those reached in the present communication.

## A MODE OF STUDYING DAMPED OSCILLATIONS BY THE AID OF SHRINKING VECTORS.

By Professor DAVID ROBERTSON, D.Sc., Member.

(Paper received 30 August, 1915.)

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- (4) Rate of change and time-integral of a shrinking sine function.
- (5) Differential equation for a shrinking sine function.
- (6) Critically-damped shrinking sine function.
- (7) Representation of exponential functions by spinning vectors.
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- (10) Overdamped oscillations.
- (11) Oscillatory discharge of a condenser.
- (12) Oscillatory charge of a condenser.

### (1) INTRODUCTION.

The application of rotating vectors to sine waves has proved of very great service in connection with the theory of alternating currents. It has enabled us to form simple mental pictures of the phase relationships, and has facilitated the deduction of formulæ by which calculations can be made. It also allows us to obtain graphical solutions of problems, but this is of less value than the two uses just mentioned.

The vector method depends on three geometrical facts. First, that the projection on a fixed line, assumed vertical, of a line of constant length rotating uniformly about one end follows the sine law. Secondly, that the projections of parallel lines are equal to one another, from which it follows that the sum of the projections of two rotating vectors is the same as that of the congruent diagonal of the parallelogram which has the two vectors for adjacent sides. In other words, any equation which is true algebraically for instantaneous values is also true vectorially for the ampli-

tudes and for the R.M.S. values which are a fixed fraction of the latter.

The third property of the vector, which has not been emphasized so much as it deserves, is that it permits a simple geometrical representation of the rate of change and of the time-integral of a sine function. The rate of change of the function is given by that of the projection which represents it, and is thus the same as the vertical component of the velocity of the extremity of the rotating vector. In other words, the rate of change of the function is given by the projection on the vertical axis of that velocity. In the case of sine waves, the velocity is at right angles to, and equal to  $\omega$  times, the vector, where  $\omega$  is the rate of rotation or angular velocity of the latter ( $= 2\pi f$ ). Consequently, the velocity is constant in amount and rotates uniformly with the original vector. The rate of change of the sine function is therefore itself a sine function, and the following well-known statement is thus obtained:—

"The rate of change of a sine function is another sine function of the same frequency, of  $\omega$  times the amplitude, and a quarter cycle ahead in phase."

Conversely, since the function is the time-integral of its own rate of change, we may say that:—

"The time-integral of a sine function is another sine function of the same frequency, of  $1/\omega$  times the amplitude, and a quarter cycle behind it in phase."

Very much of the value of the vector methods is derived from the simplicity of the last two statements. In fact, the vector method gives us a valuable means of differentiating and integrating sine functions in a simple manner without any knowledge of the calculus.



Let  $P_1, P_2, P_3$  etc., be a number of successive positions of  $P$ , so that the total time from  $P_0$  to  $P$  is divided into a large number of equal parts. Let the parts be so very small that the length of  $OP$  only changes by an insignificant fraction during each; no appreciable error is then made by assuming that the rate of shrinkage remains constant during each interval and then drops suddenly to the value applicable to the next interval which corresponds to the reduced amplitude. If the total time be  $T$  and the number of parts  $n$ , each interval is  $T/n$  and the change during each interval is  $a \times T/n$  times the mean amplitude during the interval, which is practically the same as that at its commencement. We thus have

$$\begin{aligned} OP_1 &= OP_0 (1 - a T/n), \\ OP_2 &= OP_1 (1 - a T/n) = OP_0 (1 - a T/n)^2, \\ OP_3 &= OP_2 (1 - a T/n) = OP_0 (1 - a T/n)^3, \\ OP &= OP_0 (1 - a T/n)^n. \end{aligned}$$

When the number of intervals is made very great, each becomes exceedingly small and  $(1 - a T/n)^n$ , as we saw in

This fact, which is of use when constructing the spiral, also follows from the equation; for

$$\begin{aligned} OP_1 &= \epsilon^{-aT/n}, \\ OP_2 &= \epsilon^{-aT/n} = \epsilon^{-aT/(n-1)}, \dots \dots (15) \end{aligned}$$

which does not depend on  $T_1$  and  $T_2$  so long as their difference is constant.

$OP$  makes a complete revolution in the time  $2\pi/\omega$ , during which the amplitude is reduced to the fraction  $\epsilon^{-2\pi a/\omega}$  of its original value. If we divide the revolution into  $n$  equal parts (12 is a good number, but 8 will suffice), the ratio of successive values of  $OP$  is  $\epsilon^{-2\pi a/(n\omega)}$ . The natural logarithm (to the base  $\epsilon$ ) of this fraction is  $-2\pi a/(n\omega)$ , and its common logarithm (to the base 10) is  $-0.4343 \times 2\pi a/(n\omega)$ , from which we can easily calculate it.

Multiplying  $OP_0$  by this fraction we get  $OP_1$ , the amplitude at the end of the first interval; multiplying  $OP_1$

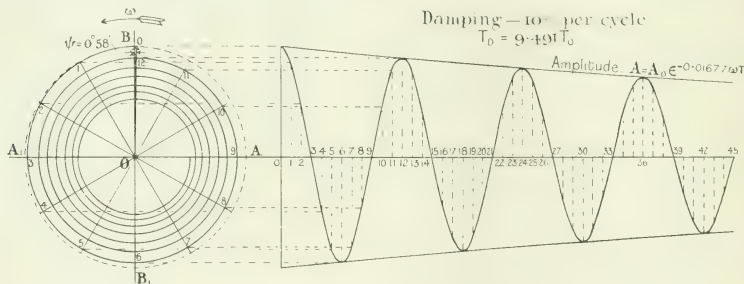


FIG. 2.—Oscillation damped 10 per cent per Cycle.

the previous section, takes the limiting value denoted by  $\epsilon^{-aT}$ . We thus see that a quantity (in this case the amplitude of the shrinking sine function) which decreases, or increases, at a rate proportional to itself is an exponential function of the time. Conversely, the rate of change of the exponential function  $\epsilon^{aT}$  is  $a$  times, and its time-integral  $1/a$  times itself. The amplitude at any time  $T$  after it has the value  $OP_0$  is thus

$$OP = OP_0 \times \epsilon^{-aT} \dots \dots (13)$$

Hence the equation to the shrinking sine function is

$$OQ = OP \times \epsilon^{-aT} \sin(\omega T + \phi) \dots \dots (14)$$

where  $\phi$  is a phase angle to take account of the initial conditions.

From the above series we see that the ratio of any two values of the amplitude is equal to  $(1 - a T/n)^m$ , where  $m$  is the number of intervals between the two instants. Hence the ratio of two amplitudes depends on the time between them and not on the particular point at which we start.

by the same fraction we get  $OP_2$ ; and  $OP_2$  by it we get  $OP_3$ ; and so on. This process is very easily carried out by the slide-rule, the accuracy of which is amply sufficient for any graphical process. In this way a number of points can be obtained and the spiral drawn through them.

The reciprocal of  $a$  is a time, and has a definite physical meaning; it is the time in which the vector would shrink to zero if it continued to shrink at the same rate as it starts to do so. If we denote this damping time-constant by  $T_0$ , the exponential function takes the form  $\epsilon^{-T/T_0}$ . Owing to the fact that the rate of shrinkage diminishes in proportion as the amplitude decays, an infinite time is actually required for the function completely to die away, and it only falls to  $1/e$  of its original value in the time  $T_0$ . After a period equal to a few times the time-constant, the amplitude has become so small that for all practical purposes it has vanished altogether. In connection with radio-telegraphy, a train of waves is considered to have ceased when its amplitude falls to 1 per cent of its initial value; this takes a time of 4.606  $T_0$ .

The amplitude falls to half value in 0.69315 times the time-constant. If then  $a/\omega$  has this value, the amplitude

falls to half value while the vector rotates through one radian. When  $a\omega = 0.69315 \approx 2\pi \approx 6.2832$ , the amplitude falls to half value in one complete period of the sine function.

The wave curve may be plotted in a manner exactly similar to that employed for the sine wave. Equidistant radial lines are drawn (12 is an excellent number, and it is convenient to use the same number for this purpose as for drawing the spiral) and their intersections with the spiral

half a cycle, as in a sine function, the crests and hollows of the wave do not occur midway between the zero points. Instead, the phase difference between a zero point and the next maximum is  $(\pi/2 - \psi)$ , while that between a maximum and the following zero is  $(\pi/2 + \psi)$ . The diagram also shows that the amplitude at any crest exceeds the crest value in the ratio of  $1 : \cos \psi$ . The point at which the amplitude curve touches the wave curve corresponds to the vertical position of the vector.

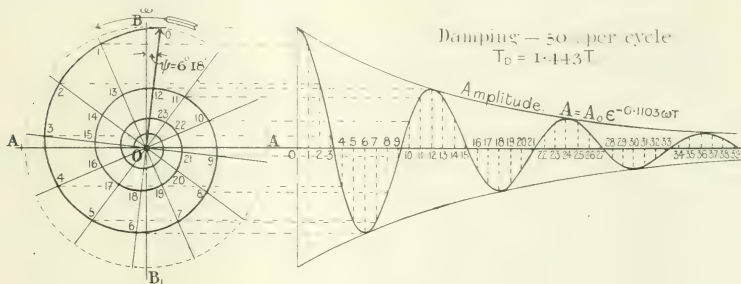


FIG. 3.—Oscillation damped 50 per cent per Cycle.

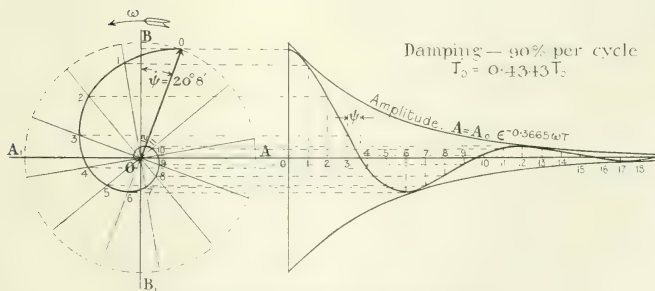


FIG. 4.—Oscillation damped 60 per cent per Cycle.

are projected on the corresponding ordinates of the wave curve. Figs. 2, 3, and 4 show such curves with different degrees of damping.

From Fig. 5 it will be seen that the maximum instantaneous value of the function during any half-cycle occurs a little before the vector reaches the vertical position, at the point where the spiral is horizontal. In the next section it is shown that OP then makes a constant angle,  $\psi$ , with the vertical, which is characteristic of the spiral, and from which it gets one of its names. We thus have the important result that although successive zero points, or successive maximum points, are separated by

If we count time from the instant when the function is at a crest, and denote that crest value by  $OQ_0$ , we see from the diagram that

$$OP_1 = OQ \cos \psi \quad (16)$$

and

$$\phi = \phi_1 - \psi \quad (17)$$

Hence the equation to the shrinking sine function may be written:—

$$OQ = \frac{OQ_0}{\cos \psi} e^{-\psi T} \sin (\omega T + \phi_1 - \psi) \quad (18)$$

As the damping is increased, the spiral becomes steeper and steeper, until finally, when  $a$  is very great compared

with  $\omega$  the spiral degenerates into a radial straight line, so that  $OP$  shrinks to zero before it has rotated to any appreciable extent. The function has thus ceased to be

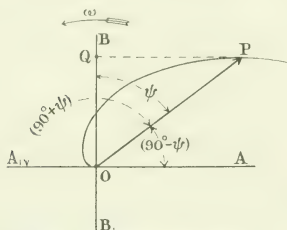


FIG. 5.—Conditions at Crest of Wave.

periodic. This particular amount of damping is known as "critical damping." For it, our equation and construction fail, and we shall treat it later by itself.

#### (4) RATE OF CHANGE AND TIME-INTEGRAL OF A SHRINKING SINE FUNCTION.

Just as with a sine function, the rate of change of  $OQ$  is equal to the component of  $P$ 's velocity parallel to  $OQ$ , and is therefore given by the vertical projection of that velocity. But  $P$  now moves along the tangent to the spiral instead of at right angles to the vector (see Fig. 6). Its velocity is

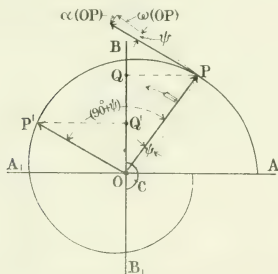


FIG. 6.—Rate of Change of a Shrinking Sine Function.

made up of two components, one  $\omega \times OP$  at right angles to  $OP$  due to the rotation, and another  $a \times OP$  along  $PO$  due to the shrinkage. Hence the total velocity of  $P$  is

$$\sqrt{[\omega \times OP]^2 + [a \times OP]^2} = \sqrt{(\omega^2 + a^2)} \times OP = \omega \times OP \quad (14)$$

and it lies ahead of the perpendicular to the vector by the angle  $\psi$ , where

$$\tan \psi = a/\omega \quad (20)$$

$$\sin \psi = a/\sqrt{(\omega^2 + a^2)} = a/\omega \quad (21)$$

$$\cos \psi = \omega/\sqrt{(\omega^2 + a^2)} = \omega/a \quad (22)$$

We can thus draw  $OP'$  at an angle  $(90^\circ + \psi)$  ahead of  $OP$  to represent the velocity of  $P$ . It therefore represents the amplitude of the rate of change of  $OQ$ , and its projection on the vertical gives the instantaneous value of that rate of change. Since  $OP'$  is proportional to  $OP$ , it shrinks at the same proportional rate, and thus  $P'$  traces out a similar spiral to  $P$ . By a suitable choice of scales, the same spiral can be made to serve for both. We thus see that:—

The rate of change of a shrinking sine function is another shrinking sine function of the same frequency, shrinking at the same proportional rate, of  $\sqrt{(\omega^2 + a^2)}$  ( $= \omega_0$ ) or  $\omega/\cos \psi$  times the amplitude, and  $(90^\circ + \psi)$  ahead in phase, where  $\tan \psi = a/\omega$ .

Since the function represented by  $OP'$  is the rate of change of that given by  $OP$ , the latter is the time-integral of the former. Consequently, we have the converse statement:—

The time-integral of a shrinking sine function is another shrinking sine function of the same frequency, shrinking at the same proportional rate, of  $1/\sqrt{(\omega^2 + a^2)}$  ( $= 1/\omega_0$ ) or  $(\cos \psi)/\omega$  times the amplitude, and  $(90^\circ + \psi)$  behind it in phase.

Thus, if the initial conditions correspond to Fig. 5 and Equations 16-18 the rate of change of the shrinking sine function may be written:—

$$(OQ)' = \frac{OQ \times \sqrt{(\omega^2 + a^2)}}{\cos \psi} \cdot e^{-\alpha T} \sin(\omega T + 180^\circ) \quad (23)$$

$$= -OQ \times (\omega + a)/\omega \times e^{-\alpha T} \sin \omega T \quad (24)$$

Draw  $PC$  perpendicular to  $P$ 's velocity, and  $OC$  at right angles to  $OP$ . Their intersection,  $C$ , is the instantaneous centre of  $P$ 's motion. For  $CP$  makes a fixed angle,  $\psi$ , with  $OP$ , and therefore rotates with the same angular velocity. But the velocity of  $P$  is

$$(\omega \times OP)/\cos \psi = \omega \times (OP/\cos \psi) = \omega \times CP \quad (25)$$

As the vectors rotate, the triangle  $OPC$  retains a fixed shape; consequently  $C$  traces out a similar spiral to  $P$ . The velocity of  $P$ , and therefore also the tangent to the spiral, is horizontal when  $CP$  is vertical; in this position,  $OP$  makes the angle  $\psi$  with the vertical. That position of the vector gives the highest or lowest point on the wave during the revolution, and thus corresponds to a crest or hollow of the wave. At this point, the rate of increase of the sine function balances the rate of decrease of the exponential function. From the diagram it is also evident that the tangent to the spiral always makes the angle  $\psi$  with the perpendicular to the vector through  $P$ ; which perpendicular is also the tangent to the circle through  $P$  having its centre at  $O$ .

The greater the damping, the greater will be the angle  $\psi$ , the steeper the spiral, and the further ahead the rate of change vector. In the limit, with critical damping,  $a$  is very great compared with  $\omega$ ,  $\psi$  is  $90^\circ$ , and  $OP'$  is exactly opposite to  $OP$ . In other words,  $P$  then moves along the radius and reaches  $O$  before the angular motion becomes appreciable.

#### (5) DIFFERENTIAL EQUATIONS FOR A SHRINKING SINE FUNCTION.

$OP$  (Fig. 7) represents a shrinking sine function, and  $OP'$  is its rate of change of  $\sqrt{(\omega^2 + a^2)}$  times the ampli-

tude and  $(\omega\psi + \psi)$  ahead in phase.  $O P''$  is the rate of change of  $O P'$ , and is a further  $(\omega\psi + \psi)$  ahead in phase and has an amplitude  $\sqrt{(\omega^2 + \alpha^2)}$  times that of  $O P'$  or  $(\omega^2 + \alpha^2)$  times that of  $O P$ .

$O R$  and  $O S$  are two vectors along  $O P$  and  $O P''$  respectively, which together balance  $O P'$ . Since they make equal angles with  $O P'$ , they must be equal to one another and the line  $S R$  is perpendicular to  $O P'$ . The relation between the lengths of these lines follows at once from the diagram.

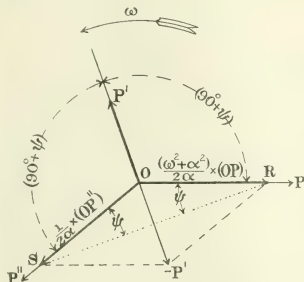


FIG. 7.—Vector Representation of the Differential Equation for a Shrinking Sine Function.

Using also the relations between the amplitudes, we get what is required ; for

$$O R = \frac{O P''}{2 \sin \psi} = \frac{O P \times \sqrt{(\omega^2 + \alpha^2)}}{2 \alpha \sqrt{(\omega^2 + \alpha^2)}} = \frac{(\omega^2 + \alpha^2)}{2 \alpha} \times O P \quad (26)$$

$$O S = \frac{O P'}{2 \sin \psi} = \frac{O P'' / \sqrt{(\omega^2 + \alpha^2)}}{2 \alpha \sqrt{(\omega^2 + \alpha^2)}} = \frac{1}{2 \alpha} \times O P'' \quad (27)$$

But  $O = O R + O P' + O S$   
vectorially for the amplitudes. (28)

$$\text{Or } O = \frac{(\omega^2 + \alpha^2)}{2 \alpha} \times O P + O P' + \frac{1}{2 \alpha} \times O P''$$

vectorially for the amplitudes. (29)

That is,  $O = (\omega^2 + \alpha^2) \times O Q + 2 \alpha \times O Q' + O Q''$   
algebraically for the instantaneous values. (30)

An equation such as this, which includes a function, its rate of change, the rate of change of its rate of change, and so on, or any two of them, is known as a differential equation. This, then, is the characteristic differential equation for a shrinking sine function. Conversely, if the equations derived from first principles for some particular problem are of this type, a shrinking sine function gives one solution of the problem.

When the differential equation is converted into the form (30), in which the coefficient of the last term (second rate of change) is unity, we see that that of the middle term (rate of change) is twice the damping velocity. Consequently the damping is determined by those constants of the vibration which gives rise to this term. For fixed values of the constants which determine the coefficient

of the first term (the function),  $(\omega^2 + \alpha^2)$  must be constant, and so we may write

$$(\omega^2 + \alpha^2) = \omega_c^2 \quad (31)$$

or

$$\omega = \sqrt{(\omega_c^2 - \alpha^2)} \quad (32)$$

where  $\omega_c$  is the rotation which the vector would have if the damping were zero. We note also that

$$\cos \psi = \omega / \sqrt{(\omega^2 + \alpha^2)} = \omega / \omega_c \quad (33)$$

We thus see that as the damping is increased—but the other factors characterizing the vibration are fixed—the rotation of the vector, and hence also the frequency of the vibration, get less and less until they become zero with critical damping, when  $\alpha = \omega_c$ . When the damping is still further increased, the quantity under the square-root sign becomes negative and its square root is then imaginary. Thus, the rotation of the vector for an overdamped vibration is an imaginary one. The function is no longer periodic, but we must defer its full consideration until we develop some further points in our theory.

#### (6) CRITICALLY-DAMPED SHRINKING SINE FUNCTION.

Since  $O Q$  is always the projection of  $O P$ , it would at first sight appear that with critical damping, when the rotation of  $O P$  is exceedingly slow,  $O Q$  must follow the same simple exponential law which applies to  $O P$ . At the same time, however, as  $\omega$  becomes very small compared with  $\alpha$ ,  $\psi$  becomes  $90^\circ$  and the initial amplitude must be exceedingly great if the initial value of the function is not to be zero.  $O P$  is still a rotating vector in spite of its slowness, and we must take account of its rotation as well as of its shrinkage. The function now takes the indefinite value  $0/0$  and must be specially evaluated.

For this purpose, we must consider the effect of the rotation when the function is near a crest while  $\omega$  is not so

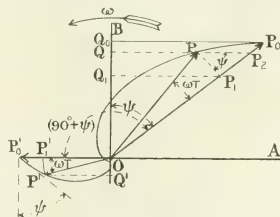


FIG. 8.—Changes near Crest of Wave.

very small. Draw the vector diagram (Fig. 8) for the initial instant at which the function has a positive crest value. Its rate of change is then zero and is about to assume a negative value. Consequently  $O P'_0$  must be drawn horizontally to the left, and  $O P_0$  is  $(90^\circ + \psi)$  behind it.

Consider the changes which take place immediately after this instant. In a very short time  $T$  the vector will have turned through a small angle  $\omega T$ , and its extremity

will have moved from  $P$  to  $P'$ . With centre  $O$  draw the arc  $P'P$  to cut  $OP$  in  $P''$ . Since the angle  $P'OP$  is very small, this arc will practically be a straight line at right angles to  $OP$ . At the same time  $P'P'$ , the continuation of  $QP$ , is perpendicular to  $OQ$ . Consequently the angle  $P'P'P = \psi$ .

The instantaneous value of the function is now  $OQ$ , whereas if the amplitude had merely shrunk to  $P'$  without rotation, it would have been  $OQ'$ . The effect of rotation has thus been to increase the function in the ratio

$$\frac{OP'}{OP} = \frac{OP' + P'P}{OP} = 1 + \frac{P'P}{OP} = 1 + \omega T \times \tan \psi \quad (34)$$

$$= 1 + aT \quad \dots \dots \dots (35)$$

Thus, whatever the value of  $\omega$ , so long as the vector is close to this initial position, the function can just as well be represented by the equation:—

$$OQ = OQ_0 \times e^{+aT} (1 + aT) \quad \dots \dots \dots (36)$$

Now, with critical damping, the vector never gets away from this position. Hence, for that condition, this equation applies during the whole time for which the function has any value at all.

We can deduce the same result from the ordinary equation, for  $OQ$

$$= \frac{OQ_0}{\cos \psi} :: e^{-aT} \sin(\omega T + 90^\circ - \psi) \quad \dots \dots \dots (37)$$

$$= OQ_0 \times e^{-aT} [\sin(\omega T + 90^\circ) \cos \psi - \cos(\omega T + 90^\circ) \sin \psi] / \cos \psi \quad (38)$$

$$= OQ_0 \times e^{-aT} \{ \sin(\omega T + 90^\circ) + \sin \omega T \tan \psi \} \quad \dots \dots \dots (39)$$

$$= OQ_0 \times e^{-aT} \{ \sin(\omega T + 90^\circ) + (\sin \omega T / \omega T \times \omega T / a / \omega) \} \quad (40)$$

$$= OQ_0 \times e^{-aT} \{ \sin(\omega T + 90^\circ) + (\sin \omega T / \omega T \times a / T) \} \quad (41)$$

$$= OQ_0 \times e^{-aT} (1 + aT) \text{ when } \omega T \text{ is very small} \quad \dots \dots \dots (42)$$

The projection of the rate of change vector would also be zero if it did not rotate; but as it is also infinitely long an infinitesimal amount of rotation produces some effect. In the small time  $T$ , its extremity moves from  $P'_0$  to  $P'$ ; the arc  $P'P'$  is practically at right angles to  $OP'_0$  and is therefore vertical. Thus, the instantaneous value of the rate of change at the time  $T$  is

$$OQ = -P'P' = -OP' \times \omega T \quad \dots \dots \dots (43)$$

$$= -OQ_0 \times \frac{\sqrt{(\omega^2 + a^2)}}{\cos \psi} e^{-aT} \times \omega T \quad \dots \dots \dots (44)$$

$$= -OQ_0 \times \frac{(\omega^2 + a^2)}{\omega} e^{-aT} \times \omega T \quad \dots \dots \dots (45)$$

$$= -OQ_0 \times (\omega^2 + a^2) e^{-aT} T \quad \dots \dots \dots (46)$$

which becomes

$$= -OQ_0 \times a^2 e^{-aT} T \quad \dots \dots \dots (47)$$

when  $\omega$  is very small.

#### (7) REPRESENTATION OF EXPONENTIAL FUNCTIONS BY SPINNING VECTORS.

Before dealing with imaginary rotations, it is necessary to devise some vectorial method of representing the simple exponential function  $e^{+aT}$ . The shrinking vector itself is a particular case of this law, but when it rotates its projection

gives a periodic function, and when it does not there is nothing to denote the passage of time. The time element can be obtained, however, by supposing the vector to spin about the projection axis, so that the plane, containing it and the axis, rotates uniformly about that axis. The vector will then sweep out a conical surface on which its extremity will trace a spiral, as in Fig. 9. We might either make the spiral steep and the spin slow, or vice versa, but it is best so to choose the spiral that the

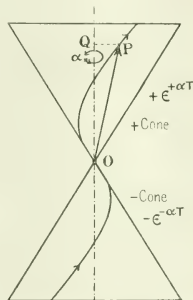


FIG. 9.—Spinning Vector for Exponential Function.

There is an infinite number of convolutions between the vertex and those shown, but the spiral is too steep to show any of them.

angular velocity of the plane is  $a$ , for in that case one standard spiral will serve most simply for all such spinning vectors. The standard spiral must be drawn so that the vector increases to  $e$  times its original amplitude\* for each radian, or  $e^{2\pi} (= 535.4)$  times for each revolution. It is also convenient to suppose the angle of the cone to be so small that the vector and its projection have the same length.

To avoid long phrases, we shall refer to the ordinary vectors as "rotating vectors" rotating about the "periodic axis," and to the exponential vectors as "spinning vectors" spinning about the "non-periodic axis."

If we add to the velocity of spin, we increase the rate of growth; that is, to increase the spin corresponds to multiplying the function by another exponential function. This remains true even when the original spin was infinitely slow. Now, we may assume that any function whatever possesses an exponential factor  $e^{a \times T}$ , for the value of the latter is always unity, and we therefore conclude that a spinning vector must always be interpreted in conjunction with the standard conical spiral.

A reversal of the spin converts a growing function into a shrinking one, or vice versa; it thus corresponds to taking the reciprocal of the exponential factor.

A change of phase will increase or decrease the function according to whether it is forwards or backwards, and the ratio depends on the amount of the phase displacement.

\* It is convenient to denote the length of the vector as its amplitude, whether it is a rotating one or a spinning one.

To change the phase is thus equivalent to multiplying the function by a number whose natural logarithm is equal to the forward change of phase.

If the cone and spiral be continued beyond the vertex, after an infinite time a shrinking vector will reach the vertex and pass on to the other half of the cone. It then becomes a growing one of the opposite sign. We thus see that  $+\epsilon^{+aT}$  is a continuation beyond infinity of  $-\epsilon^{-aT}$ , and  $-\epsilon^{+aT}$  of  $+\epsilon^{-aT}$ . It should be noted that the upward or downward way of the vector is determined by the sign of the function and not by that of the spin.

#### (8) IMAGINARY ROTATION.

We are now in a position to deal with imaginary rotation, which we can write in the form  $j\omega$ , where  $\omega$  is a real quantity and  $j^2 = -1$ , from which it follows that  $i/j = j/j^2 = -j$ . The geometry of rotating vectors gives us one interpretation for  $j$ . We can reverse a vector by multiplying it by  $-1$ ; that is by  $j^2$  or twice by  $j$ . But we can also reverse it by turning it twice in one plane through a right angle. We thus conclude that to multiply such a vector by  $j$  is equivalent to turning it forwards through a right angle, and that to divide it by  $j$  is to turn it back by the same amount, or to turn it forward and then reverse it.

Similarly, we can reverse a rotation viewed from a fixed point by multiplying the angular velocity by  $j^2$  or twice by  $j$ . We can also reverse it by turning the axis twice in one plane through a right angle. We shall consider multiplication by  $j$  to imply a positive rotation, and shall regard as positive an angular movement which is anticlockwise when viewed from the positive side of the origin of co-ordinates. Multiplication of a rotation by  $j$  then turns the positive end of its axis down through a right angle, which is equivalent to turning it up but reversing the rotation. Division turns the axis up without reversal.

Since a shrinking sine function has ceased to be periodic when the damping is raised to the critical amount, we must so choose the plane in which to turn the axis that the projection of the vector does not vary periodically as rotation takes place. Consequently the axis of imaginary rotation must be the axis on which we project to get the instantaneous values; that is, it is the non-periodic axis of spin just considered, which we have seen must always be taken in conjunction with the standard conical spiral. In other words, a vector with imaginary rotation is really a spinning vector; and conversely, one with an imaginary spin is really a rotating vector. We can thus state:—

Dividing a rotation about the periodic axis by  $j$  converts it into a spin of the same sign about the non-periodic axis; multiplying by  $j$  converts it into a reversed spin about the latter.

And conversely,

Multiplying a spin about the non-periodic axis by  $j$  converts it into a rotation of the same sign about the periodic axis; dividing it by  $j$  converts it into a reversed rotation about the latter.

#### (9) HYPERBOLIC SINES AND COSINES.

So far the instantaneous values of our functions have not been given by the rotating vectors but by their projections on a vertical line; the rotating vector has only been the

amplitude. A sine or cosine function can, however, quite easily be represented by a pair of equal vectors having equal but opposite rotations. Thus, in Fig. 10, two equal rotating vectors starting together from the vertical with rotations  $\omega$  and  $-\omega$  always make the same angle,  $\omega T$ , with the vertical, and consequently have their resultant

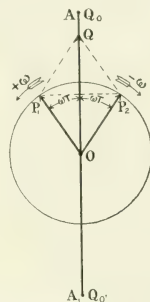


FIG. 10.—Two Rotating Vectors Equivalent to a Cosine Function.

along that line. The length of the resultant is  $2 \cos \omega T$  times that of each vector. We thus have

$$\cos \omega T = \frac{1}{2} \left[ \sqrt{\overset{+}{\omega}} + \sqrt{\overset{-}{\omega}} \right] \text{ vectorially.} \quad (48)$$

Since  $\omega = (j\omega)/j$ , a rotation  $\omega$  about the periodic axis is equivalent to a spin  $j\omega$  about the non-periodic axis. We thus have

$$\cos \omega T = \frac{1}{2} (\epsilon^{j\omega T} + \epsilon^{-j\omega T}) \quad \dots \quad (49)$$



FIG. 11.—Two Rotating Vectors Equivalent to a Sine Function.

If we reverse the negatively rotating vector, as in Fig. 11, the resultant lies along the horizontal and its length is  $2 \sin \omega T$  times that of each vector. To bring it back to the vertical we must divide it by  $j$ . Thus

$$\sin \omega T = \frac{1}{2} \left[ \sqrt{\overset{+}{\omega}} - \sqrt{\overset{-}{\omega}} \right] / j \quad \dots \quad (50)$$

$$= (\epsilon^{j\omega T} - \epsilon^{-j\omega T}) / 2j \quad \dots \quad (51)$$

We have thus deduced the exponential values of the sine and cosine from the properties of our spinning vectors.

Similarly,

$$\cos \omega T = \frac{1}{2} \left[ \left( \sqrt{j\omega} + \right) + \left( \sqrt{j\omega} - \right) \right] \quad (52)$$

$$= \frac{1}{2} (\epsilon^{-\omega T} + \epsilon^{+\omega T}) \quad (53)$$

$$= \cosh \omega T \quad (54)$$

$$\text{and } \sin \omega T = \frac{1}{2} \left[ \left( \sqrt{j\omega} + \right) - \left( \sqrt{j\omega} - \right) \right] j \quad (55)$$

$$= \frac{1}{2} (\epsilon^{-\omega T} - \epsilon^{+\omega T}) j \quad (56)$$

$$= \frac{1}{2} (\epsilon^{-\omega T} - \epsilon^{+\omega T}) j \quad (57)$$

$$= j \sinh \omega T \quad (58)$$

The functions  $\cosh \omega T$  and  $\sinh \omega T$  (pronounced "cosh" and "shine") are known as the hyperbolic cosine and sine of  $\omega T$ . They are the cosine and sine of an imaginary angle of rotation, and we have seen how to interpret these in terms of the spinning vector.

We commenced this section by showing that the cosine and sine functions were respectively the vectorial sum and difference of two equal rotating vectors of half the amplitude and having equal but opposite rotations. Similarly, we now see that the hyperbolic cosine and sine are respectively the sum and difference of two equal spinning vectors of half the amplitude and having equal but opposite spins.

#### (10) OVERDAMPED OSCILLATIONS.

When the damping exceeds the critical value, we have seen that the rotation takes the imaginary value  $j\omega$ . The angle  $\psi$  is also imaginary, for

$$\tan \psi = a'j\omega = -ja'\omega \quad (59)$$

$$\sin \psi = a/\sqrt{(a^2 - \omega^2)} \text{ which is greater than unity} \quad (60)$$

$$\cos \psi = \pm \omega/\sqrt{(a^2 - \omega^2)} \quad (61)$$

The equation for the oscillation then becomes

$$OQ = \frac{OQ_0}{\cos \psi} \times \epsilon^{-aT} \sin(j\omega T + 90^\circ - \psi) \quad (62)$$

$$= OQ_0 \times \epsilon^{-aT} \cos(j\omega T - \psi)/\cos \psi \quad (63)$$

$$= OQ_0 \times \epsilon^{-aT} (\cos j\omega T \cos \psi + \sin j\omega T \sin \psi)/\cos \psi \quad (64)$$

$$= OQ_0 \times \epsilon^{-aT} (\cos j\omega T + \sin j\omega T \tan \psi) \quad (65)$$

$$= OQ_0 \times \epsilon^{-aT} \left( \cos j\omega T + \frac{a}{\omega} \sin j\omega T \right) \quad (66)$$

Interpreting this equation in terms of the spinning vectors (Equations 52 and 57) we get

$$OQ = OQ_0 \times \frac{1}{2} \epsilon^{-aT} (\epsilon^{+\omega T} + \epsilon^{-\omega T}) + \frac{a}{\omega} (\epsilon^{+\omega T} - \epsilon^{-\omega T}) \quad (67)$$

$$= OQ_0 \times \frac{1}{2} \epsilon^{-aT} (1 + a'\omega \epsilon^{+\omega T} + (1 - a'\omega) \epsilon^{-\omega T}) \quad (68)$$

Similarly, the equation for the rate of change (see Equation 24) of the overdamped oscillation becomes

$$(OQ)' = -OQ_0 \times \frac{(a^2 - \omega^2)}{j\omega} \epsilon^{-aT} \sin j\omega T \quad (69)$$

$$= -OQ_0 \times \frac{(a^2 - \omega^2)}{\omega} \epsilon^{-aT} \times \frac{1}{j} \sin j\omega T \quad (70)$$

$$= -OQ_0 \times \frac{(a^2 - \omega^2)}{2\omega} \epsilon^{-aT} (\epsilon^{+\omega T} - \epsilon^{-\omega T}) \quad (71)$$

#### (11) OSCILLATORY DISCHARGE OF A CONDENSER.

When oscillations are started in an oscillatory circuit by suddenly closing it while the condenser is charged, the total electromotive force is zero, and consequently its three components—resistance, inductance, and dielectric electromotive forces—must balance one another. That is, at every instant

$$0 = E_R + E_L + E_C \quad (72)$$

$$= RI + L \cdot I' + \frac{1}{C} \cdot Q \quad (73)$$

Remembering that the charging current is the rate of growth of the charge, and that the rate of change of the current is consequently the second rate of change of the charge, we can put the equation into the form:—

$$0 = Q + CR \cdot Q' + LC \cdot Q'' \quad (74)$$

$$= \frac{1}{LC} Q + \frac{R}{L} \cdot Q' + Q'' \quad (75)$$

We at once recognize this as the typical differential equation for a shrinking sine function. Certain relations between the constants may be noted before proceeding

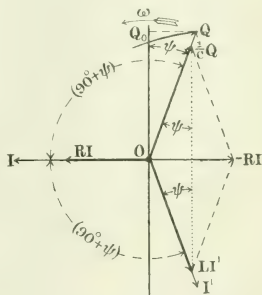


FIG. 12.—Vector Diagram for Oscillatory Discharge of Condenser.

further. Both the ratio  $L/R$  and the product  $CR$  are periods of time which have a well-known significance with reference to the circuit. If the condenser is replaced by a battery of negligible resistance and the circuit be suddenly closed, the current begins to grow at such a rate that it would reach its final value ( $E/R$ ) in the time  $L/R$ . This is the inductive time-constant

$$T_1 = L/R \quad (76)$$

If, on the other hand, the inductance be removed and a constant electromotive force be suddenly impressed in the circuit, the condenser begins to charge at such a rate that if it continued to do so at the same rate it would be fully charged ( $Q = CE$ ) in the time  $CR$ . This is the dielectric time-constant of the circuit,

$$T_2 = CR \quad (77)$$

The quantity  $\sqrt{LC}$  is the geometrical mean of the other two time-constants; for

$$1/\omega = \sqrt{LC} = \sqrt{(1/L)(CR)} = \sqrt{T_1 T_2} \quad (29)$$

It is the time that would be taken for the vector to rotate through one radian if the resistance had been negligible. By inserting  $T_1$  and  $T_2$  in the equations instead of their equivalents in terms of  $R$ ,  $L$ , and  $C$ , the equations take a somewhat simpler form.

We shall draw the vector diagram (Fig. 12) for the instant at which the circuit is closed and the oscillations started. At that instant the condenser contains its original charge; the current is zero, but is about to flow in the discharging, or negative, way.  $OI$  must therefore be drawn horizontally to the left, and  $OQ$ , its time integral, is  $90^\circ + \psi$  behind it and has  $1/\omega\sqrt{w^2 + a^2}$  times its amplitude.  $OL$ , its rate of change, is the same amount ahead, and has  $(\omega^2 + a^2)$  times its amplitude.

From the geometry of the diagram we can see that the initial amplitude of the charge is

$$\frac{Q}{\cos \psi} = \frac{\sqrt{w^2 + a^2}}{\omega} Q \quad (30)$$

and that of the current is

$$\frac{\sqrt{w^2 + a^2}}{\cos \psi} \cdot Q = \frac{(\omega^2 + a^2)}{\omega} \cdot Q \quad (30)$$

The diagram also gives the initial phases and so we can write

$$Q = \frac{Q}{\cos \psi} \epsilon^{-aT} \sin (\omega T + 90^\circ - \psi) \quad (31)$$

$$= Q \times \frac{\sqrt{w^2 + a^2}}{\omega} \epsilon^{-aT} \sin (\omega T + 90^\circ - \psi) \quad (32)$$

$$\text{And } I = Q \times \frac{(\omega^2 + a^2)}{\omega} \epsilon^{-aT} \sin (\omega T + 90^\circ - \psi) \quad (33)$$

$$= -Q \times \frac{w + a}{\omega} \epsilon^{-aT} \sin \omega T \quad (34)$$

We can easily determine  $\omega$ ,  $a$ , and  $\psi$  in terms of  $R$ ,  $L$ , and  $C$ , by equating the corresponding coefficients of the typical differential equation and the one obtained for our problem; but we can almost as readily obtain them directly from the vector diagram.

Draw  $RI$  along  $OI$ , and balance it by two vectors  $LI'$  and  $i/C \cdot Q$  along  $OI'$  and  $OQ$  respectively. These form two sides of a parallelogram of which  $-RI$  is the diagonal. The last two vectors must be equal to one another since they make equal angles with  $OI$ , and the line joining their extremities is consequently at right angles to  $OI$ . Using the geometry of the diagram, and the known relationships between the amplitudes,  $I_0$ ,  $Q_0$ , and  $I_0$ , we can get what we require; for

$$RI_0 = 2LI_0 \sin \psi = 2L \sqrt{w^2 + a^2} I_0 \times \frac{a}{\omega \sqrt{w^2 + a^2}} = 2LI_0 \frac{a}{\omega} \quad (35)$$

$$\therefore a = R/2L = 1/2T_1 \quad (36)$$

$$\text{Or } T_1 = 1/a = 2L/R = 2T_2 \quad (37)$$

$$\text{Also } i/C \cdot Q_0 = LI_0' \quad (38)$$

$$\therefore \frac{1}{C} \times \frac{Q_0}{\cos \psi} = LI_0' = L \times \frac{a}{\omega} \times \frac{1}{\cos \psi} \quad (39)$$

$$\therefore \omega + a = 1/C \times \frac{1}{\cos \psi} = \frac{1}{T_1 \cos \psi} \quad (40)$$

$$\therefore \omega^2 + a^2 = \frac{1}{L^2 C^2} (1 - \cos^2 \psi) = \frac{1}{L^2 C^2} \sin^2 \psi \quad (41)$$

$$= \frac{1}{L^2 C^2} (1 - \frac{C^2 R^2}{4L^2}) = \frac{1}{4L^2 C^2} (4L^2 - C^2 R^2) \quad (42)$$

$$\text{And } 2\pi f = \omega = \frac{1}{\sqrt{LC}} \sqrt{1 - \frac{C^2 R^2}{4L^2}} = \frac{1}{\sqrt{LC}} \cos \psi \quad (43)$$

$$= \frac{1}{\sqrt{LC}} \sqrt{1 - \frac{CR}{4LR}} = \frac{1}{\sqrt{LC}} \sqrt{1 - T_1/4T_2} \quad (44)$$

Also

$$\sin \psi = \frac{a}{\omega + a} = \frac{R/2L}{1/L \times \frac{1}{\sqrt{LC}} \sqrt{1 - \frac{CR}{4LR}}} = \sqrt{\frac{CR}{4LR}} = \sqrt{T_1/4T_2} \quad (45)$$

$$\cos \psi = \frac{1}{\omega + a} = \sqrt{1 - \frac{CR}{4LR}} = \sqrt{1 - T_1/4T_2} \quad (46)$$

$$\text{and } \tan \psi = \frac{a}{\omega} = \frac{R/2L}{1/L \times \frac{1}{\sqrt{LC}} \sqrt{1 - \frac{CR}{4LR}}} = \frac{1}{\sqrt{1 - \frac{CR}{4LR}}} = \frac{1}{\sqrt{1 - T_1/4T_2}} \quad (47)$$

$$= \frac{1}{\sqrt{1 - \frac{CR}{4LR}}} = \frac{1}{\sqrt{1 - T_1/4T_2}} \quad (48)$$

$$= \frac{1}{\sqrt{1 - \frac{CR}{4LR}}} = \frac{1}{\sqrt{1 - T_1/4T_2}} \quad (49)$$

$$\text{Putting these values in Equations 82 and 84 we get}$$

$$Q = \frac{Q}{\sqrt{1 - \frac{CR}{4LR}}} \epsilon^{-R/2LT} \sin \left[ \frac{1}{\sqrt{1 - \frac{CR}{4LR}}} \sqrt{1 - \frac{CR}{4LR}} T \right] \quad (50)$$

$$+ 90^\circ - \sin^{-1} \sqrt{\frac{CR}{4LR}} \quad (51)$$

$$= \frac{Q}{\sqrt{1 - T_1/4T_2}} \epsilon^{-T/2T_1} \sin \left[ \sqrt{1 - \frac{T_1}{4T_2}} T \right] \quad (52)$$

$$+ 90^\circ - \sin^{-1} \sqrt{\frac{T_1}{4T_2}} \quad (53)$$

$$\text{and } I = \frac{-Q}{\sqrt{LC} \sqrt{1 - \frac{CR}{4LR}}} \epsilon^{-R/2LT} \quad (54)$$

$$\sin \left[ \frac{1}{\sqrt{1 - \frac{CR}{4LR}}} \sqrt{1 - \frac{CR}{4LR}} T \right] \quad (55)$$

$$= \frac{-Q}{\sqrt{1 - T_1/4T_2}} \epsilon^{-T/2T_1} \sin \left[ \sqrt{1 - \frac{T_1}{4T_2}} T \right] \quad (56)$$

$$\sin \left[ \sqrt{1 - \frac{T_1}{4T_2}} T \right] \quad (57)$$

$$= \frac{-Q}{\sqrt{1 - T_1/4T_2}} \epsilon^{-T/2T_1} \sin \left[ \sqrt{1 - \frac{T_1}{4T_2}} T \right] \quad (58)$$

$$\sin \left[ \sqrt{1 - \frac{T_1}{4T_2}} T \right] \quad (59)$$

$$\text{Critical damping occurs when } 4L/R = CR, \text{ or } R^2 = 4L/C, \text{ or } 4T_1 = T_2. \text{ Using Equations 42 and 47 we get}$$

$$Q = Q \times \epsilon^{-RT/2L} \left[ 1 + (R/2L)T \right] \quad (60)$$

$$= Q \times \epsilon^{-T/2T_1} (1 + T/2T_1) \quad (61)$$

$$\text{and } I = -Q \times R/2L \times \epsilon^{-R/2LT} \quad (62)$$

$$= -\frac{Q}{4T_1} \times \epsilon^{-T/2T_1} T \quad (63)$$

$$= -\frac{Q}{4T_1} \times \epsilon^{-T/2T_1} T \quad (64)$$

$$\text{when } CR > 4L/R, \text{ or } R^2 > 4L/C, \text{ or } T_2 > 4T_1, \text{ the oscillation is overdamped. Making use of Equations 68 and 71 we get}$$

$$Q = \frac{1}{2} Q \epsilon^{-R/2LT} \left[ 1 + \left( 1 - \frac{4L/R}{CR} \right)^{-1} \right] \epsilon^{\frac{T}{\sqrt{LC}} \sqrt{\frac{CR}{4LR} - 1}} \quad (65)$$

$$+ \left[ 1 - \left( 1 - \frac{4L/R}{CR} \right)^{-1} \right] \epsilon^{\frac{T}{\sqrt{LC}} \sqrt{\frac{CR}{4LR} - 1}} \quad (66)$$

$$= \frac{1}{2} Q \epsilon^{-T/2T_1} \left[ 1 + \left( 1 - \frac{4T_1}{T_2} \right)^{-1} \right] \epsilon^{\frac{T}{\sqrt{LC}} \sqrt{\frac{T_2}{4T_1} - 1}} \quad (67)$$

$$+ \left[ 1 - \left( 1 - \frac{4T_1}{T_2} \right)^{-1} \right] \epsilon^{\frac{T}{\sqrt{LC}} \sqrt{\frac{T_2}{4T_1} - 1}} \quad (68)$$

$$= \frac{1}{2} Q \epsilon^{-T/2T_1} \left[ 1 + \left( 1 - \frac{4T_1}{T_2} \right)^{-1} \right] \epsilon^{\frac{T}{\sqrt{LC}} \sqrt{\frac{T_2}{4T_1} - 1}} \quad (69)$$

$$+ \left[ 1 - \left( 1 - \frac{4T_1}{T_2} \right)^{-1} \right] \epsilon^{\frac{T}{\sqrt{LC}} \sqrt{\frac{T_2}{4T_1} - 1}} \quad (70)$$



# THE MAGNETIC TESTING OF BARS OF STRAIGHT OR CURVED FORM.

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(Paper received 20 July, 1915.)

## SYNOPSIS.

- (1) Introductory.
  - (2) Measurement of  $H$  by search coils.
  - (3) and (4) Construction and calibration of search coils.
  - (5) Null method of measuring  $H$ .
  - (6) Simple apparatus for high magnetization.
  - (7) Hysteresis loops, remanence, and coercivity.
  - (8) Typical permeability curves.
  - (9) Ring yoke apparatus.
  - (10) Reversible search coils for  $H$  measurement.
  - (11) Tests on curved bars.
  - (12) Concluding remarks.
- Appendix. The Chattock magnetic potentiometer.

## (1) INTRODUCTORY.

For the accurate testing of magnetic materials, until recently it has been the usual practice to employ a uniformly magnetized test-piece, the condition of uniformity being ensured by using a closed magnetic circuit of ring form. This ring form of test-piece has some disadvantages: it is somewhat difficult to construct, it necessitates rather laborious winding of coils on each specimen, and, unless rings of rather large diameter are used, it is not suitable for high values of the magnetization. For this reason all kinds of methods have been proposed and used, of varying degrees of accuracy, for the testing of material in the form of bars, whether straight or curved. The main difficulties in all these methods have been (1) to obtain uniformity of magnetization all along the specimen, and (2) to determine the true value of the magnetizing field  $H$  which produces this desirable result. As a rule it has been the custom to complete the magnetic circuit as well as possible by a yoke or yokes, and to deduce the mean value of  $H$  from the number of applied ampere-turns; the unavoidable magnetic leakage, however, is apt to introduce considerable error in the determination of the  $H$ .

## (2) MEASUREMENT OF $H$ BY SEARCH COILS.

These difficulties will be avoided if we can find a method for the direct measurement of the  $H$  at any portion of the bar. The  $H$  is equal to the flux density in the air at the surface of the portion dealt with, and can be determined by means of a small search coil placed very close to the surface of the iron, the axis of the coil being parallel to that surface and in the direction of  $H$ .

If the coil be connected to a ballistic galvanometer, the throw, when the coil is quickly removed to a region of zero field, gives the required value of  $H$ ; whereas if the coil is kept in the original position, any throws on the galvanometer scale only measure the changes of  $H$  from

its initial value. (Such a coil, if connected to a suitable voltmeter, can be used to measure an alternating  $H$ .) This method of determining the changes in  $H$  appears to be due to Ewing and Low, who used it in their Isthmus Method\* of testing a small cylindrical rod at high magnetizations. A search coil is wound over the central portion of the rod, and over this a second coil of the same number of turns, but of slightly greater diameter is wound. These coils, when connected in opposition, form what may be conveniently called a *differential* (or, for round rods, *annular*) search coil; such a differential coil takes no account of the magnetic flux in the iron, but will indicate any changes of flux in the area between its two component coils.

The use of one or more single search coils placed very near to the iron, but not interlinked with it, has several advantages over the differential system. Madame Curie†

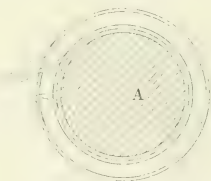


FIG. 1.

used a search coil in this way to determine the demagnetizing field at the centre of a straight permanent magnet; but the valuable development of the system by the use of very flat search coils was carried out by Denso,‡ and after him by Gumlich and Rogowski.§ The coils we have used in the National Physical Laboratory are of various designs according to the form of the specimen to be tested, some being differential (circular or rectangular) and others single and usually very flat. These two kinds are illustrated in Figs. 1, 2, and 3, the last-mentioned figure showing a single flat coil.

In all cases it is desirable that the whole of the effective

\* *Proceedings of the Royal Society*, vol. 42, p. 200, 1887; *Philosophical Transactions of the Royal Society*, A, vol. 180, p. 221, 1889. Also J. A. EWING: "The Magnetic Circuit in Iron and other Metals," 1st edition, p. 132.

† *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, Series 5, vol. 3, p. 37, 1868. Also *Electrical Review*, vol. 44, p. 40, 1899.

‡ Dissertation, Rostock.

§ *Elektrotechnische Zeitschrift*, vol. 11, p. 202, 1912.

area of the coil shall be as near to the surface of the iron as possible, otherwise the value of  $H$  obtained may not be the true field acting on the iron. This will usually be the case when the distribution of the magnetic field around the bar is not uniform. Unfortunately in most instances in practice the value of  $H$  varies somewhat with the distance from the surface of the bar. It is important to know

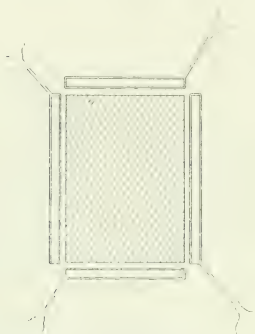


FIG. 2.

the rate of variation near the surface, in order to be able to estimate with what degree of accuracy the search coil reading gives the true value of  $H$  at the surface. For this purpose in May 1913 we adopted the expedient of winding a third coil ( $c$ ) over the two (differential) coils ( $a$  and  $b$ ). By opposing coils  $b$  and  $c$  an outer differential coil is formed with an annular area farther from the iron

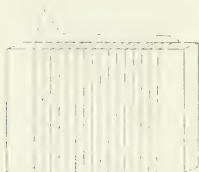


FIG. 3.

surface than that between  $a$  and  $b$ . A comparison of the values of  $H$  obtained with the inner and outer annular coils gives a measure of the radial rate of variation of  $H$ .

Dr. E. Gumlich\* has improved on this arrangement by adding a fourth coil, so as to obtain a still better idea of the variation of  $H$  with the distance from the iron surface. In a similar way two or more flat search coils may be used, one over the other. If they all have the same values of

$N_2 s$ , the area-turns, they can even be used differentially to give direct measurements of the variation of  $H$ .

In an appendix a description is given of another form of search coil, the Chattock magnetic potentiometer, which has a number of valuable applications in the testing of non-uniform magnetic circuits. It is intimately connected with the methods here described.

### (3) CONSTRUCTION OF THE SEARCH COILS.

The authors have wound many of the differential search coils on small bobbins made entirely of ebonite, the inner shell of the bobbin being turned as thin as possible (to about 0.5 mm.). Coils on such bobbins can be used for measuring alternating fields, and, as explained below, this is a considerable advantage. If only direct-current fields are to be used, the bobbin can be constructed more easily and strongly by building it of a thin-walled metal tube (brass, etc.) with ebonite cheeks. Especially when the cross-section of the iron rod is small it is essential to wind the coils with extremely thin wire, so as to keep very close to the iron and yet have the product,  $(\text{No. of turns}) \times (\text{difference area})$ , sufficiently great for good sensitivity. With enamelled wire of 0.07 mm. diameter (diameter of copper, 0.06 mm.), 1,000 turns can be got into a winding space of about 6 sq. mm. Where the iron section is larger, it is better to use silk-covered wire, which is more trustworthy for insulation. The leads of all search coils should be run very closely together; and it is convenient to surround them with thin silk tubing.

The design of the flat search coils is simpler and easier. They are wound on thin plates of insulating material. Ebonite is an easily worked material which can be used, but it is scarcely permanent enough, especially if the coils are to stand a temperature of 30° to 40° C., which may happen when very high magnetizations have to be reached. We find that for the smaller coils thin plates of glass (0.8 mm. thick) with ground edges form very convenient cores. The turns, which may be in several layers, are held in place by a winding of silk thread across them, the whole being made solid by paraffin wax or varnish. These flat coils cannot be used with iron rods of circular section, but we have succeeded in constructing semi-circular coils which can be fitted close up to the surface of round rods. They are wound on flat paper cores, well varnished with cellulose acetate enamel, bent round into tunnel shape and allowed to dry hard.

We should mention here that the ballistic galvanometer used by us was a very sensitive one, having a resistance of 280 ohms and a sensitivity of 800 millimetres at 1 metre distance per microcoulomb, with a complete period of 8.5 seconds. For a less sensitive instrument the dimensions or number of turns of the search coils would have to be increased.

### (4) CALIBRATION OF SEARCH COILS.

For search coils used to measure  $H$ , in general it is only necessary to know two constants of the coil, namely its resistance and  $N_2 s$ , the product of the number of turns and the mean area. For coils by which the total flux ( $\Phi$ ) is measured, we need only know  $N_2$ ; if  $B$  is to be determined,  $s$  should also be known. The number of turns is usually counted when the coil is being wound. In dif-

\* *Archiv für Elektrotechnik*, vol. 2 (11), p. 361, 1914.

ferential coils it is absolutely essential that the inner and outer coils shall have exactly equal numbers of turns. Sometimes the mean area can be deduced with accuracy from the dimensions of the coil, but as a rule it is best to determine the  $N_2 s$  by placing the coil in a known magnetic field or by determining the mutual inductance between the coil and a suitably wound solenoid or other standard coil. Let the search coil be placed coaxially at the centre of a long solenoid (or other coil) giving a sufficiently uniform field  $H$  through the search coil for a current of  $I_1$  amperes in the solenoid.

Then  $H = b I_1$ ,

where  $b = 4\pi N_1 / 10 l$  for a long solenoid of length  $l$  and of  $N_1$  turns.

If  $M$  be the mutual inductance (in henries) between the solenoid and the search coil, then

$$M = 10^{-8} N_2 s H / I_1 = 10^{-8} N_2 s b.$$

Hence  $N_2 s = 10^8 M / b = 10^8 M / 4\pi N_1$  . . . . . (1)

The value of  $M$  can be determined by any of the ordinary methods such as those of Maxwell or Carey Foster, or by means of a direct-reading inductometer.† If both the search coil and the solenoid are constructed without solid metal, so as to be free from eddy currents, it is best to make the measurement with alternating current and a vibration galvanometer or telephone, as this gives much increased sensitivity, which is so desirable when the search coil is very small. We have found it convenient to combine the standard solenoid with the inductometer

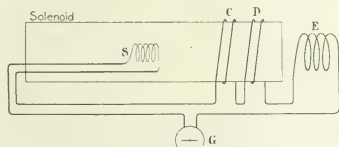


Fig. 4.

in the following way. The solenoid forms the primary circuit of the inductometer, while the secondary circuit is formed by two 10-strand coils fixed near the end of the solenoid and brought to two sets of studs giving mutual inductances of 5, 10, 15, 20 . . . and 50, 100, 150 . . . microhenries, a small movable coil, with a pointer and scale, giving the finer subdivision. The search coil  $S$  (in Fig. 4) is placed at the centre of the solenoid and connected (in opposition) to the secondary circuit  $CDE$  and the galvanometer or telephone at  $G$ .  $C$ ,  $D$  and  $E$  are adjusted until the throw on reversal (of the primary current) is zero, or, when alternating current is used, until the vibration galvanometer or telephone indicates a balance.

\* For a solenoid which cannot be considered as infinitely long, the constant  $b$  is given approximately by the formula  $b = 4\pi N_1 \cos \phi / 10 l$ , where  $\tan \phi = \text{diameter} \div l$ . When  $\tan \phi$  is small,  $b = 4\pi N_1 (1 - \frac{1}{2} \tan^2 \phi)$ .  
† A. CAMPBELL, *Proceedings of the Physical Society*, vol. 20, p. 626, 1906-7, and vol. 21, p. 66, 1907-9; also *Philosophical Magazine*, vol. 14, p. 404, 1907, and vol. 15, p. 155, 1908.

If the secondary circuit consists of only one subdivided coil, the  $N_2 s$  of the search coil can be found by interpolation from two throws on the ballistic galvanometer.

#### (5) NULL METHOD OF MEASURING $H$ .

When either  $B$  or  $H$  is measured by the help of a search coil, the simplest procedure is to observe the throw on a calibrated ballistic galvanometer when the  $B$  (or  $H$ ) is either reduced to zero or reversed. It has been suggested by C. W. Burrows\* that for measuring  $B$  a null method could be used in which the change of flux in the iron is balanced against the change of flux in air produced by the same magnetizing current in an adjustable mutual inductance. With a ballistic galvanometer of moderately long period (8 seconds) we have not found this method workable, for the "iron flux" and the "air flux" rise at such different rates that the galvanometer light-spot nearly always gives a double kick, and an exact balance is out of the question. Moreover we have not been able to get over the difficulty by the use of condensers or other means of smoothing out the sudden voltage impulses. The measurement of  $H$ , however, by this null method does not present nearly so much difficulty, for the "air flux" by which the  $H$  is determined often follows much the same curve of rise (or fall) as that in the secondary coil of the mutual inductance. When this is the case the null method may be safely employed. The unfavourable cases are those in which the  $H$  to be measured is considerably affected by free magnetism, which occurs in regions near leaky parts of the magnetic circuit. As will be explained below, in certain tests the measurements are much facilitated by the use of mutual inductance to balance out part of the flux through the search coil.

#### (6) SIMPLE APPARATUS FOR HIGH MAGNETIZATION.

In May 1913 we set up a very simple modification of Ewing and Low's Isthmus Method. In the original form of this method rather elaborate coned pole-pieces are required, with accurate mechanism by which the test-bar along with these pole-pieces can be quickly turned end for end in a strong magnetic field. This system is illustrated in Fig. 5, in which the small test-rod  $A$  fits into the coned pole-pieces  $B$  and  $C$ , the whole being rotatable between the poles  $NS$  of a powerful electromagnet. A much simpler system, shown in Fig. 6, was found to be quite satisfactory. Instead of the cones, thick soft-iron disks  $E$  and  $F$  form the pole-pieces, and these do not touch the magnet poles, but are separated from them by small air-gaps (1 or 2 mm. distance). The test-piece  $D$  is fitted into central holes in the flat pole-pieces, which are clamped in an independent frame so that they can be removed together from between the poles. Instead of reversing the direction of the test-piece, the magnet is so designed as to allow quick reversal of the magnetic field. It consists (Fig. 7) of a well laminated iron core of nearly square section (8 cm.  $\times$  7 cm.) formed of ring stampings of about 22 cm. mean diameter, the polar air-gap  $ab$  being about 8 cm. across. The winding consists of about 1,000 turns of copper wire of 2 mm. diameter (No. 14 S.W.G.), with a total resistance of about 2.2 ohms.

\* Bulletin of the Bureau of Standards, vol. 6, p. 31, 1910.

The whole construction is extremely simple; the laminated magnet had not been specially designed for the purpose. The entire absence of fitted or clamped magnetic joints is a distinct advantage from the point of view of construction, and appears to have no disturbing effect in the tests, although the presence of the outer air-gaps lowers somewhat the maximum  $H$  obtainable in the central gap.

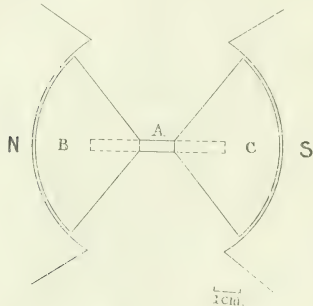


FIG. 5.

*Variation of  $H$  with magnetizing current.*—When the pole-pieces are not inserted, the  $H$  at the centre of the wide air-gap is practically proportional to the magnetizing current (over the working range), 10 amperes giving a central  $H$  of 800. In the normal case with the pole-pieces leaving a central air-gap of 1.3 cm., when a test-

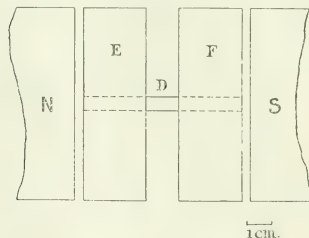


FIG. 6.

rod is in position, the  $H$  near the middle of the rod is very nearly proportional to the current, the relation between them depending slightly on the section and magnetic quality of the test-piece  $D$ . For example, with a certain iron rod

$$H = 390(I - 0.2)$$

for a range of  $I$ , from 1 ampere upwards.

Thus 10 amperes will give  $H = 3,820$ .

*Form of test-piece.*—The specimen tested is in the form either of a rod 7 cm. long and 0.5 cm. in diameter, or an equivalent bundle of strips or wires. One of the chief objections to the whole system lies in the smallness of the specimen tested, which does not allow such good sampling and increases the relative effects of the mechanical treatment (turning, cutting, etc.) used in preparing the sample. At the high magnetizations for which this apparatus is intended, the effects of the preliminary mechanical treatment are, however, comparatively trifling. This was proved by various experiments. For example, a bundle of strips was tested from  $H = 150$  up to  $H = 2,500$ . Each strip was then cut in two longitudinally by shears, all being considerably bent and re-straightened in the process. The results on retesting showed a slight lowering of the permeability below  $H = 500$ , but above that value the effect of the cutting was practically negligible. It does not seem essential that the strips should be so closely packed as nearly to fill the holes in the pole-pieces, for, when the section of the bundle is reduced by 50 per cent

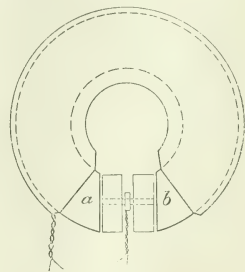


FIG. 7.

by removing some of the strips, the total observed reduction in permeability is only of the order of 1 per cent. From  $H = 1,000$  up to  $H = 3,000$ , rods shorter than 7 cm. gave satisfactory results so long as they entered the holes in the pole-pieces to a depth of at least 0.5 cm.

*Time lag of electromagnet.*—With such a large electromagnet, when the current is suddenly reversed, difficulties may occur due to the slowness with which the reversed current rises. A rough calculation showed that in the worst case the current reaches 99.3 per cent of its full value 0.5 second after the circuit is closed. When experimentally investigated, several effects due to time lag were distinctly observed, but with a ballistic galvanometer of 8 seconds' complete period the possible errors due to this cause appeared to be practically negligible.

*Uniformity of  $H$ .*—At the middle point of the test-rod is placed a small ebonite bobbin with an inner winding of 40 turns for measuring  $B$ , and three outer coils of 400 turns each, used differentially as already described, for determining  $H$ . These coils are of enamelled copper wire of 0.6 mm. diameter (No. 46 S.W.G.); with an axial length of 4 mm., the mean diameters of the inner and outer annuluses being 6 mm. and 12 mm. respectively. From the

results of a large number of experiments with various materials it has been proved that the magnetic field round the central portion of the rod is wonderfully uniform from  $H = 150$  up to  $H = 3,000$ . One rarely finds the field shown by the outer annular coil to be as much as 1 per cent greater than that given by the inner one. Explorations of the whole interpolator space by means of a minute search coil (of 3 mm. mean diameter and 400 turns) have corroborated these results.

*Correction for inductive area.*—With rods of small section, and more particularly with small bundles of strip, the difference between the cross-section of the iron and the area of the search coil for B is considerable, and this necessitates a large correction on the observed value of B. If  $s = \text{area of iron, } s_s = \text{search coil area not occupied by iron, then True B} = \text{Observed B} - H_s/s_s$ . The correction increases in proportion to H. To avoid the trouble of applying this varying correction to each observation, we have found it convenient to eliminate the term  $H_s/s_s$  by means of a compensating device shown in Fig. 8.

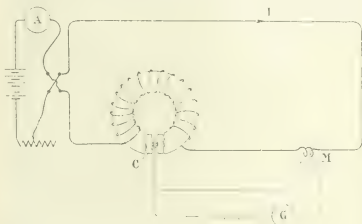


FIG. 8.

A small mutual inductometer  $M$  is arranged with its primary coil in series with the magnetizing circuit of the magnet, and its secondary coil connected in opposition to  $C$ , the search coil for  $B$ , in the ballistic galvanometer circuit. As will be seen below, the interpolar value of  $H$  is approximately proportional to  $I_m$ , the magnetizing current; thus

$$H \leq h I_n.$$

where  $h$  is approximately known. Now let the small inductometer be set so that

$$M = 10^{-1} h s_{\perp}$$

If  $\Phi'$  be the flux in the secondary coil of M, due to current  $I_1$ , then

$$\Phi' = 10^{-1} M I_1 = h s_1 I_1 = H s_1,$$

and hence the inductometer automatically subtracts the term  $H s_i/s$  and gives the true value of  $B$  for all values of  $H$ . A range of from 0 to 50 microhenries is convenient.

## (7) HYSTERESIS LOOPS, REMANENCE, AND COERCIVITY.

The apparatus can be used, not only for the determination of permeability curves, but also for hysteresis loops, including the remanence and coercive field. The remanent magnetism of the electromagnet, although it makes its

appearance, does not introduce any errors, since the true values of  $H$  are given by the search coils. As there has been some uncertainty amongst technical people as to the meaning of the term "coercive field" (or "coercive

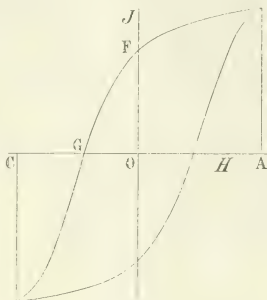


FIG. 9.

force"), we shall give the definition (following Madame Curie\*) before discussing the methods of measuring such field. Let a uniform ring of magnetic material be brought (by preliminary demagnetization and repeated

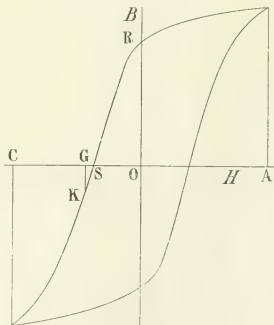


FIG. 19.

reversals of the maximum  $H$ ) into the steady cyclic state shown by the hysteresis loop in Fig. 9, the curve giving the corresponding values of  $H$  and  $J$ , where  $J$  is the intensity of magnetization and  $= (B - H)/4\pi$ . Here  $OA = -OC = H_{\text{max}}$ . If  $H$  be now reduced to zero,  $OF$  represents the remanent intensity, the corresponding value of  $B$  being called the remanence ( $OR$  in Fig. 10).

\* *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, Series 5, vol. 3, p. 37, 1898; and *Electrical Review*, vol. 44, p. 40, 1899.

When, after reducing  $H$  from the value  $OA$  to zero, we proceed round the loop from  $F$  to  $G$  by a gradually increasing negative  $H$ , then the "coercive field or force" ( $H_c$ ) is  $OG$ , i.e. the reversed  $H$  which makes  $J=0$ . When this is the case  $B=H$ . In the  $H-B$  curve of Fig. 10  $KG=OG$ . Both the remanence and the coercive field depend on the maximum  $H$  for which the loop has been drawn. If  $H_{max}$  is increased, both of them tend to become constant as magnetic saturation is approached. The coercive field corresponding to saturation has been called by Madame Curie the "coercivity" of the material, and is one criterion of its quality as regards permanence of magnetization.

Hopkinson's\* definition of coercive force is slightly different from the above, being "the reversed magnetic force necessary to make  $B=0$  after the material has been submitted to high magnetizing force."

[Hopkinson remarks, "The coercive force must not be confused with that (other) value of the reversed  $H$  which leaves the iron completely demagnetized."]

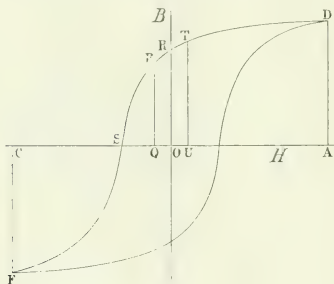


FIG. 11.

In most practical cases, such as with magnet steels, Hopkinson's definition gives a value almost coincident with the coercivity as defined above, since  $d B/d H$  is very large where the loop curve crosses the axis of  $H$ . Hence in most cases  $OS$  may be taken as equal to  $OG$  (Fig. 10), and all the measurements may be taken in terms of  $B$  instead of  $J$ .

We have begun by defining the terms for a closed uniform magnetic circuit, but the definitions hold for any piece of magnetic material throughout which the  $H$  and  $B$  are uniform; for example, for a small element of any non-uniform open magnetic circuit. If the corresponding values of the actual  $H$  and  $B$  are all determined by suitable search coils, the loop so drawn will be quite correct and give the true values of the remanence and coercive force, in spite of the fact that the  $H$  may have a large component due to the action of free magnetism (demagnetizing action of free poles). As the size of the search coils cannot be indefinitely diminished, in practice their dimensions must be so chosen as to average the

$H$  and  $B$  over a portion of the material throughout which the want of uniformity is not too great.

The determination of the remanence and coercive field is most important for hardened steel used for permanent magnets, and here the tests must be made with high values of  $H_{max}$  (say 400 to 500). In determining the coercive force corresponding to a high value of  $H_{max}$ , the galvanometer throw measuring the coercive force ( $H_c$ ) is usually small compared with the throw due to  $H_{max}$ , and it becomes rather difficult to read the small throw with sufficient accuracy. In order to increase the accuracy, one way is to raise the sensitivity of the galvanometer and to balance out accurately the complete throw from  $+H_{max}$  to  $-H_{max}$  by the help of an adjustable mutual inductance connected similarly to that described above for the correction of  $B$ . For magnet steels the most accurate results are obtained by the following procedure:—

- (1) Starting from the point  $D$  (Fig. 11), and using the  $B$  search coil, we find by trial the value of the current ( $-I_c$ ) which corresponds to the point  $S$ . For this the  $B$  throw from  $D$  to  $S$  must be half the complete throw from  $D$  to  $E$ .
- (2) The mutual inductance in the  $H$  search-coil circuit is now set by trial, until on commutating the maximum current ( $+I_{max}$  to  $-I_{max}$ ) no throw is obtained as we pass from  $D$  to  $E$  on the curve.
- (3) Starting from  $D$ , the current is switched off ( $I_{max}$  to 0) and we arrive at and determine a point  $P$  on the curve. Usually the point  $P$  will not coincide with  $R$ , the true remanence point, owing to the residual field due to the remanent magnetism of the yoke, effect of free poles, etc. This residual  $H$  is measured by  $OQ$ , and may be either positive or negative, as  $P$  may sometimes come on the positive side of the axis  $OB$ , depending on the relative values of the coercive field in the yoke and the test-bar.
- (4) The mutual inductance is now set to zero. From current  $I=0$  we pass to  $I=-I_c$ , the value determined in (1), thus going from  $P$  to  $S$ . The throw with the  $H$  coil gives  $QS$ , and finally the coercive field  $= OQ + QS$ .
- (5) As the curve  $DRP$  for magnet steel is usually very flat, the remanence point  $R$  can be got with fair accuracy from the four points  $E, S, P, D$ , already determined. For higher accuracy, a point  $T$  near  $R$  is found as follows: The current is dropped from  $+I_{max}$  to a small positive value, and by the help of the  $B$  coil the height of the ordinate  $TU$  is obtained. Then the current is switched off, reaching the point  $P$  (already determined), and by the  $H$  coil  $UQ$  is measured. Since  $OQ$  has been found,  $OU$  is now known and the position of the point  $T$  is completely determined. From the points  $P$  and  $T$  the remanence point  $R$  can now be more accurately found.

In the above procedure it has been assumed that the commutating switch is arranged with two rheostats according to the Ewing system, which affords the capability of reaching any point on the loop and of completing the cycle after each step. In the mutual inductance method the accuracy is somewhat lessened by the fact that the

\* Hopkinson's "Collected Researches," vol. 2, p. 166.

balance obtained with M is rarely quite exact, a small double throw usually remaining.

#### (8) TYPICAL PERMEABILITY CURVES.

In Fig. 12 are given a number of H-B curves obtained by the apparatus already described, the samples being in the form of thin rods or bundles of strips. As will be seen

The general agreement with similar curves already published by Gumlich\* is interesting. In the case of the very pure electrolytic iron the agreement is close; for saturation the intensity of magnetization [i.e.  $(B-H)/4\pi$ ] deduced from our curve is 1717, which appears to be practically identical with the value 1719 given by Gumlich.

It appears, however, that this is not the maximum value

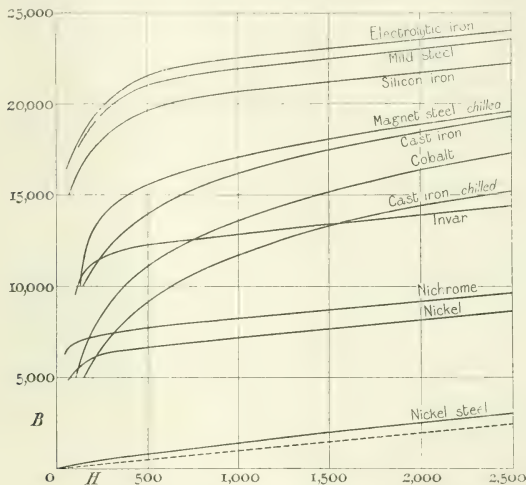


FIG. 12.

from the following list, most of the materials are of interest from a practical point of view.

- Electrolytic iron.
- Mild steel.
- Silicon iron sheet.
- Magnet steel (chilled). Tungsten 3·3 %, carbon 0·75 %.
- Cast iron, before chilling.
- Cast iron, chilled.
- Cobalt (commercial).
- Invar. Iron 74 %, nickel 36 %.
- Nichrome.
- Nickel, electrolytic. Ni 98·8 %, Fe 0·6 %, Cu 0·2 %, Mn 0·3 %.
- Nickel steel. Ni 19·9 %, C 0·41 %, Mn 0·96 %.

The lowest curve in the diagram is the straight line for air (permeability = 1). All the other curves ultimately tend to become parallel to the air line as the magnetization is increased, close parallelism indicating that the material has reached the condition of magnetic saturation.

that can be obtained with very pure iron, for B. O. Peirce† found the value 1740 for Norway iron. According to P. Weiss‡ cobalt iron (30 % Co) gives a still higher value.

#### (9) RING YOKE APPARATUS.

In the apparatus already described (§ 5) the main disadvantage is that the rods tested must be of small diameter. For testing round rods up to 2·5 cm. in diameter the authors have constructed a special apparatus of a type somewhat similar to Gumlich's most recent design.§ The general arrangement is shown in Fig. 13.

The test rod A, surrounded by a bobbin wound with a magnetizing coil C, is clamped, by the help of suitably bored iron end-pieces E E, between the two circular yokes Y Y. F F are pieces of hard wood to equalize the pressures. (For bars of rectangular section the end pieces E E

\* *Elektrotechnische Zeitschrift*, vol. 30, pp. 1065 and 1069, 1909.

† *Proceedings of the American Academy of Arts and Sciences*, vol. 49, p. 117, 1913.

‡ *Comptes Rendus*, vol. 156 (1), p. 1070, 1913.

§ *Archiv für Elektrotechnik*, vol. 2, p. 461, 1914.

are not bored, but merely faced flat.) In order to increase the uniformity of the magnetizing field near the middle part of the central bobbin, there are two additional magnetizing coils K K, and the yokes also are wound with coils with their turns somewhat crowded towards each of the magnetic joints. All of the magnetizing coils are in series. The central solenoid has 950 turns of No. 16 S.W.G. wire (1.63 mm. diameter), coils K K 150 turns each, and the

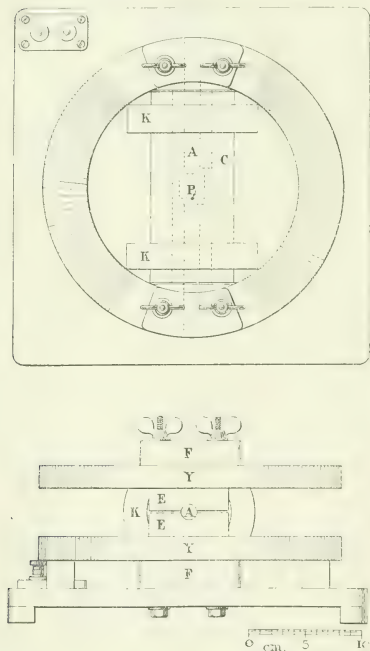


FIG. 13.

yokes a total of 200 turns. A current of 12 amperes gives  $H \approx 1,000$ .

Experiments showed that the additional windings greatly improved the radial uniformity of  $H$  at the middle of the bar for the range  $H = 50$  to 150, but slightly decreased the uniformity at higher ranges ( $H = 400$ ). On the whole the average improvement is satisfactory, and appears to exclude errors greater than 1 per cent. Without further precautions the apparatus should not be used for permeability tests with values of  $H$  below 30. The  $H$  and  $B$  search coils are on a small bobbin P at the middle part of

the test bar. For a rod of 1.25 cm. diameter each annular  $H$  coil has 1,800 turns, the innermost coil being at a mean radial distance of about 2.5 mm. from the surface of the iron. With bars of rectangular section flat search coils are used, which have the advantage of getting much closer to the iron surface (mean distance  $\approx 1.5$  mm.); two coils in series may be used, one on each side of the bar. It may be mentioned that the authors have also made satisfactory tests on rectangular bars of magnet steel in a short solenoid (22 cm. long) heavily wound and without any yoke. Very good uniformity of  $H$  can be ensured by extending the effective length of the bar by butting against its ends two soft-iron bars of about 20 cm. in length.

#### (10) REVERSIBLE SEARCH COILS FOR $H$ MEASUREMENT.

In all the methods in which the  $H$  search coils are kept in a fixed position with regard to the iron, the throws

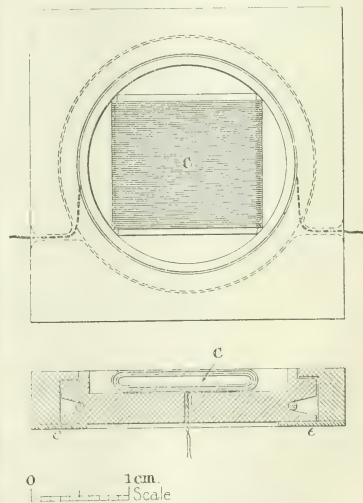


FIG. 14.

on the galvanometer can only determine changes in  $H$  and not (directly) the absolute values. These values can be determined by pulling the search coil (where possible) quickly out of the field. In general it is difficult to do this, and, even when it is possible, a double throw of the galvanometer may occur, which vitiates the accuracy of the test.

A much better way is to mount a flat search coil so that it can be rotated in a plane parallel to the direction of  $H$  (i.e. usually parallel to the surface of the iron). It can then be quickly reversed in position (turning through  $180^\circ$ ),

and, when calibrated in a known magnetic field, will give directly the absolute value of  $H$  at any moment. The mounting of a very narrow reversible coil of this kind is shown in Fig. 14.

The search coil  $c$  is mounted in a thin pulley (5 mm. thick) which can turn in a cell of ebonite with a thin German-silver cheek ( $ee$ ) forming the second bearing. Two threads from the pulley (one of which can be fastened to a spring if desired) allow the coil to be reversed from the outside. Adjustable stops, not shown, limit the turning to  $180^\circ$ .

Tests on bars of magnet steel by this method are in agreement with the results given by fixed search coils. The method is the simplest and most straightforward that we have tried.<sup>6</sup> Further experience will show how far it is adaptable to various kinds of tests.

#### (11) TESTS ON CURVED BARS.

In practice it is desirable to be able to test curved as well as straight bars, for example the magnets of horse-shoe form used in magnetos. If the curvature is not too great, the  $H$  at any part may be measured by means of search coils near the surface, as already described. For the horse-shoe magnets, flat search coils are tied (inside and outside) at the middle of the bend, and over the whole are slipped five or more magnetizing coils. As the values of  $H$  have to be large (up to 400 or 500), nearly all the available space is filled up with these coils, some of them being wound wedge-shaped to fit the bend. In spite of such heavy winding, the tests have to be made very quickly to avoid undue heating. It is usual to complete the magnetic circuit by placing a soft-iron armature across the poles, but even if this is omitted the values found for the remanence and coercive field are scarcely affected. In a test of this kind it is a common practice to deduce the mean value of  $H$  from the total number of magnetizing turns and the mean length of the magnet. When there is an armature across the poles this method usually gives the coercive field with fair accuracy, but the remanence may be wrong by several per cent. This can be shown by experiment, and is due to the fact that allowance cannot be easily made for the part of the total magnetomotive force used up in the armature and joints. We have found by experiment (with search coils) that, when an armature is used, there is good uniformity of  $H$  along the greater part of the magnetic circuit.

#### (12) CONCLUDING REMARKS.

In this paper we have described a number of different methods, partly with a view to illustrate their historical development, but more particularly to offer to the practical experimenter a variety from which he can choose what is most suitable for his samples and instrumental equipment. The essential feature of all these methods is that the value of the magnetizing  $H$  is not calculated from the somewhat indefinite length of the magnetic circuit and the ampere-turns, but is directly measured by the help of a search coil placed as near as possible to the surface of the iron. We trust that the details given here may be of assistance to other experi-

menters in this field, in which there is still ample scope for further development. We hope ourselves to improve and simplify some of the methods in the near future.

In conclusion we would express our best thanks to Mr. H. C. Booth, A.R.C.Sc., for skilful help in a number of the experiments, and to Dr. R. T. Glazebrook, C.B., F.R.S., Director of the Laboratory, for kind assistance and advice.

### APPENDIX.

#### THE CHATTOCK MAGNETIC POTENTIOMETER.

Twenty-eight years ago Professor A. P. Chattock\* described a beautifully simple arrangement for measuring directly the difference of magnetic potential between any two (accessible) points. In spite of the accuracy and convenience of the system, it has not come into such general use as it deserves. It has, however, been in practical use for many years in the test-room of one of the large manufacturing firms in this country. Quite recently it has been re-invented by Rogowski,† who has described a number of interesting and valuable applications. We cannot do better than quote Chattock's description, slightly altering his notation for the sake of uniformity.



FIG. 15.

"Let  $P$  and  $Q$  (Fig. 15) be two points in a magnetic field connected by any line (straight or curved) of length  $l$ ; and let  $H$  represent magnetic force resolved along  $l$ . Then, if  $\gamma$  be the difference of [magnetic] potential between  $P$  and  $Q$ ,

$$\gamma = \int H dl \dots \dots \dots (2)$$

"If, instead of points,  $P$  and  $Q$  represent two equal plane surfaces of area  $s$ , and  $\bar{\gamma}$  be their average difference of potential,

$$\bar{\gamma} = \int \gamma d\bar{s} = \int H dU,$$

$U$  being the volume of a tube of constant cross-section,  $s$ , connecting  $P$  and  $Q$  by any path.

"Now let a wire helix be wound uniformly upon such a tube, with  $N$  turns per unit length, and allow  $H$  to vary with time,  $t$ . Provided there be no magnetic substance inside the helix, an electromotive force  $\epsilon$  will be set up in the latter, such that

$$\epsilon = \frac{d}{dt} \int H dl s dN = \frac{d}{dt} N \int H dU = N s \frac{d\bar{\gamma}}{dt} \dots (3)$$

"The value of  $\epsilon$  is thus proportional to the rate of change of  $\bar{\gamma}$ ; and to this alone, if external inductive effects are guarded against by winding the wire in an even number of layers ( $N$  and  $s$  being constant). Hence if the wire be connected with a ballistic galvanometer, and  $\bar{\gamma}$  be altered

\* *Philosophical Magazine*, vol. 24, p. 94, 1887; *Proceedings of the Physical Society*, vol. 6, p. 25, 1888; and *Beiblätter zu den Annalen der Physik und Chemie*, vol. 12, p. 121, 1888.

† W. ROGOWSKI and W. STEINHAUS. "Die Messung der magnetischen Spannung." *Archiv für Elektrotechnik*, vol. 1, p. 141, 1913. Also W. ROGOWSKI, *Ibid.*, vol. 1, p. 511, 1913.

\* Many years ago Ayrton and Mather introduced "trigger" coils which turned quickly through  $180^\circ$  for the purpose of measuring flux densities in air. *Electrician*, vol. 35, p. 674, 1895.

suddenly from  $\gamma_1$  to  $\gamma_2$ , the needle of the galvanometer will be thrown through the angle  $\theta$  such that

$$\gamma_1 - \gamma_2 = k \sin \theta / 2 \quad (4)$$

and the combination forms what may be called a magnetic potentiometer.

"In exploring a permanent field with such an apparatus, the best way is, perhaps, to fix one end of the helix in a clip, thereby keeping its potential constant, and to move the other end from point to point in the field. For this purpose the wire should be wound upon a flexible core, the average length of which, whether bent or straight, must be constant (otherwise  $d s d N$  will not be equal to  $N d U$ ) . . . ."

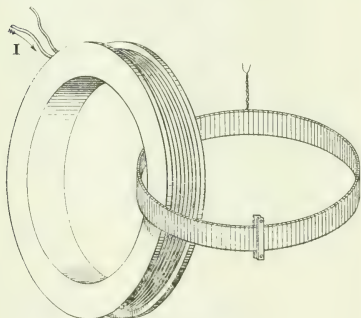


FIG. 16.

If  $IN\Phi$  be the total flux turns in the helix, another way of expressing the fundamental relation is

$$IN\Phi = Ns \int_P^Q H dl \quad (5)$$

where P and Q indicate the ends of the helix. This corresponds to Rogowski's final equation.

**Calibration.**—To find the constant  $k$ , the helix is slipped through a coil of  $N_1$  turns and its ends are brought close together (Fig. 16) forming a complete uniform toroidal coil.

If a current  $I_1$  be started in the coil, the total magnetomotive force due to it will be  $0.4 \pi N_1 I_1$ , and hence

$$0.4 \pi N_1 I_1 = k \sin \frac{\theta}{2} \quad (6)$$

Thus by observing  $I_1$  and the throw  $\theta$ , and knowing  $N_1$ , the constant  $k$  can be immediately found.

The above is Chattock's system of calibration in combination with a ballistic galvanometer; it requires a measurement of the current  $I_1$  and includes the constant of the galvanometer.

The real constant of the helix is  $Ns$  [Equation (3)], namely the number of area-turns per centimetre.

To determine this constant once for all, the helix A (Fig. 17) is linked with the coil C of  $N_1$  turns.

The mutual inductance between them is balanced, as

shown, by the variable inductance M, using either reversed direct current and a ballistic galvanometer, or alternating current and a telephone or vibration galvanometer. When a balance is obtained

$$Ns = \frac{N_1 s}{l} = 10^9 M / (4 \pi N_1) \quad (7)$$

where  $N_1$  is the total number of turns on the (toroidal) helix. It is interesting to notice that this formula (7) is identical with Equation (1) for the calibration of a search coil in a long solenoid.

When we remember that a current in a uniformly wound toroidal coil produces no magnetic field outside the coil, and that a long straight solenoid may be taken, at its central portion, as equivalent to a toroidal coil of the same mean pitch, the identity of the mutual-inductance equations is immediately explained.

**Practical construction.**—In one form of Chattock's instrument the cross-section was circular, the helix being

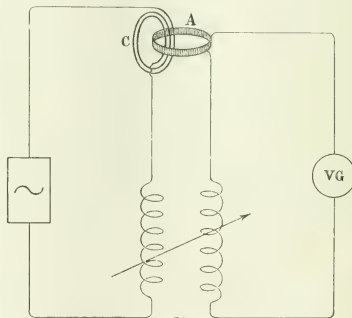


FIG. 17.

wound (in a screw-cutting lathe) upon a core of flexible gas-tubing made of plaited and varnished canvas. The spaces between the turns were sometimes filled with soft cotton thread to keep the turns uniformly distributed.

In Rogowski's type the core consists of a strip of press-spahn from 2 to 7 cm. wide, as illustrated in Fig. 18.

In his second paper cited above, he discusses a number of problems in which the instrument gives valuable assistance. One or two of these may be here mentioned.

- (a) Magnetic joints can easily be tested; for example, the joint between the rail and the shoe in a magnetic track brake.

Magnetic potential difference =  $0.4 \pi \times$  ampere-turns.

By calibration in a coil with  $N_1 I_1$  ampere-turns, we can read directly the number of ampere-turns used up in the joint. In fact we can at once apportion the expenditure of ampere-turns in each respective part of a magnetic circuit (e.g. the yoke, air-gap, joints, etc., in a dynamo).

- (b) The spiral may be connected to an alternating-current instrument (for example, a thermal or electrostatic voltmeter, a vibration galvanometer or an oscillograph). In this way interesting tests may be made on transformers and other apparatus.
- (c) The numbers of turns in two coils may be compared by linking the helix through each of them, and proceeding as in the calibration [Equation (6)]; or alternating current may be used as in (b).

We would suggest the mutual inductance method [Equation (7)] as being the most accurate for such comparisons. Rogowski points out that under certain circumstances it is possibly advantageous to use an iron

core, and the current  $I_1$  is adjusted until the needle shows no deflection, then the magnetic potential difference from P to Q is equal and opposite to the magnetomotive force applied by the current  $I_1$ . Just as with the air-core instrument, the direct current in a cable can be measured by looping the magnetic circuit round the cable. Goldschmidt also suggested the use of a search coil instead of the magnetic needle.

*Tests on bars.*—The application of the magnetic potentiometer to the testing of iron bars has been recently made by F. Goltze.\* His system is shown in Fig. 19.

The test rod (or bundle of strips) A is placed across the poles of a powerful electromagnet. The central portion of A carries S, the search coil for B, while the ends of the

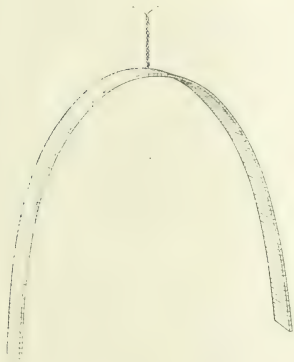


FIG. 18.

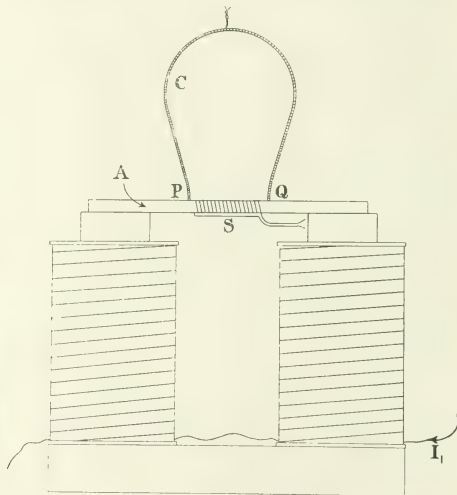


FIG. 19.

core in the helix. In this connection it is of interest to mention the magnetic potentiometer of R. Goldschmidt,† which is designed for just the same kind of measurements as can be made with Chattock's instrument.

In the Goldschmidt apparatus an iron core is divided in the middle, leaving an air-gap in which is pivoted a magnetic needle after the manner of the Ewing permeability bridge.‡

Near each end of the core is wound a coil of a known number of turns, and by sending a measured current  $I_1$  through these coils any desired magnetomotive force can be applied. If the ends of the core are placed at P and

helix C are placed against the rod at P and Q. Either S or C can be connected to a ballistic galvanometer, and, from the throws obtained when various values of  $I_1$  are reversed, the H, B curve of the sample can be obtained.

The mean value of H along PQ

$$= (Y_P - Y_Q) / (\text{length PQ}).$$

The author gives results showing satisfactory agreement with other methods.

A flat search coil placed along PQ would give the mean value of H just as well in this particular case, but the flexible helix allows various lengths of the bar to be more readily examined.

\* *Electrician*, vol. 54, p. 207, 1904.

† Compare also the compensating yoke in the Ilivici permeameter (*Bulletin de la Société Internationale des Electriciens*, 3rd Ser., vol. 3, p. 581, 1913).

\* *Archiv für Elektrotechnik*, vol. 2, p. 303, 1914.

## SCOTTISH LOCAL SECTION: CHAIRMAN'S ADDRESS.

By D. A. STARR, Member.

*(Address delivered 9 November, 1915.)*

I need not remind members of this Local Section that their first Chairman, the late Lord Kelvin, was one of the most eminent electrical engineers the world has ever produced. It has been suggested that, in honour of his memory, the Annual Dinner of this Section should be named after him; and I think it would be only befitting when we have an opportunity again of celebrating this annual function, that we should follow the precedent set up by a kindred association, who, instead of using the name of their Institution on such occasions, name their Annual Dinner after one of the most prominent figures in the engineering profession and thereby perpetuate the memory of James Watt.

I should like to refer to two other predecessors in this position, namely, the late Mr. Henry A. Mavor, who passed away during the last few months leaving behind him the record of a distinguished career in both theoretical and practical electrical work, and the late Captain E. George Tidd, who for so many years was connected with this Section as its Honorary Secretary and afterwards as Chairman. On the outbreak of war Captain Tidd offered his services voluntarily for either home or foreign duty, and with the most unselfish willingness abandoned his business activities, gave up all the comforts of a pleasant home life for the rigor and exposure of the trenches, and was killed in action, a glorious ending to a useful and active life—all honour to his memory.

Many members are now on military service; a month ago their number had reached 1,150—617 holding commissions. About 30 have been killed or reported missing, and many more have been wounded or taken prisoners. This is not a bad showing out of a membership of 6,944.

My connection with electrical engineering dates from the early days of street-lighting development—30 years ago—and it is most interesting to look back over this period and note the marvellous progress which the electrical industry has made during this time.

It was just 36 years ago last month that Thomas Edison introduced his first commercially-successful incandescent lamp. This had an efficiency of 7 watts per candle. The regular manufacture of these lamps was commenced at Menlo Park in 1880, the efficiency of the lamp then being something like 5 or 6 watts per candle. During that year 25,000 lamps were sold in the United States. In 1913 the annual output of electric lamps in the United States had increased to 80 millions, this figure including all makes of incandescent lamps.

The tungsten lamp was commercially introduced in 1907, and 52,500 were sold that year in the United States. In 7 years the sales had increased to 52½ millions per annum, and to-day we have lamps with an efficiency of ½ watt per candle, which, I think, represents about 1,400 per cent better efficiency than was shown with Edison's first commercial lamp.

The development in generating plant has been no less remarkable. Thirty years ago I remember that a 50-light arc dynamo or a 500-incandescent-lamp 100-volt belt-driven set was considered quite a large installation. This would be equivalent to a modern 25-kw. set. Now we have single turbo-generators rated at 30,000 to 40,000 kilowatts with line voltages up to 150,000, and a great improvement in efficiency has been effected.

The cost of production and supply of electrical energy has been reduced in this period to about one-half of 1 per cent of what it cost the previous generation. It is hardly conceivable that the same rate of progress can continue, but the supply and distribution of electrical energy from large central stations where a cheap supply of fuel is available, combined with the development of our water powers, may tend to still further reductions.

All these improvements were carried out under conditions where scientific research and commercial competition worked hand in hand during a period of national peace.

To-day, however, the position is changed. We are passing through one of the most momentous periods in the world's history, and through a crisis unparalleled in the annals of the Empire. While deploring the necessity, it is a source of the greatest gratification to those of us who have assisted in the adaptation of electricity to many useful purposes, that electricity is playing such an important part in the successful carrying out of the war.

The many applications of electricity on war vessels, from the super-dreadnought to the submarine and mine sweeper, are now so important that without this agent our Navy could not maintain its place in defending our shores, nor hold the supreme command of all the seas.

Ordnance of all kinds is traversed, elevated, aimed, and fired by electricity. Torpedoes are discharged and guided on their course by the same means. Dark places on board ship are lighted, power is supplied for searchlights, winches, and other auxiliaries, and instantaneous communication is established between the bridge, the conning tower, and the magazine. Submarine signalling is carried on, and wireless telegraphy and its applications are too well known to require minute description here.

I am firmly convinced that the electrical propulsion of ships, so strongly advocated by the late Henry Mavor, will soon become a practical commercial reality. American engineers have realized this fact already, and are building and equipping some large warships on this principle.

In land warfare the field telephone is one of the most practical applications to which I can refer. Many of our brave fellows owe their lives to the connecting link between the men in the trenches, their reinforcements, and the artillery in the rear. The latter get their information as to the direction and range of their fire by this means, or by wireless messages from the reconnoit-

ing aircraft ; whilst on the latter electricity is almost indispensable.

Motor cars, which transport our food-stuffs, ammunition, and other material to the front, would be much less effective were it not for the dynamos and batteries which start, control, and regulate their motive power. In numerous instances electrically-propelled trams have proved exceedingly useful, and we have heard of cases where wire entanglements have been rendered much more effective by being energized with high-tension current.

In our hospitals electro-medical apparatus has greatly aided the operating staff in quick and correct diagnoses of bullet, shrapnel, and other wounds, and has helped considerably to alleviate suffering.

It has been frequently represented by our military and naval authorities that this war cannot be carried to a successful issue without the thorough co-operation of those who are engaged in the manufacture of war munitions, and it has often been said that the men in overalls are doing their duty to their country equally with the men in khaki or blue.

The output of ammunition must essentially be large, as it is necessary that there should be from this country an output sufficient to supply not only our own Army and Navy, but also to assist the resources of our Allies. This output has been enormously increased by the full, prompt, and economical use of the power supplies of the country, not only for munitions, but for the construction of additional warships and attendant craft, the manufacture of guns for naval and land use, transport wagons, material of all sorts for aircraft, and the hundred-and-one things required to carry on successful warfare on its present colossal scale, on sea, on land, and in the air. Such sources of power supply, thanks to the far-seeing enterprise of engineers, investors, councillors, and Local Government Boards, have developed materially during the past few years, and I think we compare favourably, on the whole, with any other industrial country in the utilization of our resources.

After the outbreak of war, great activity developed in the completion of warships already on the stocks, and in the construction of additional ships. Munitions of all kinds, and material for war purposes, were wanted, and were wanted quickly. The location of large municipal and company-owned electrical undertakings over the greater portion of industrial Britain put into the hands of the Government a lever, of which they have taken full advantage. Shell, bomb, and other munition factories, large and small, have started all over the country, and many more are in course of construction. The majority have derived and will derive their power at very short notice from central generating stations, each being able to hand over to the Government its particular contribution to the great work, in every case at a reasonable cost to the country. Many adaptations have been made in works and factories which have been long established in ordinary commercial manufacture, and these have reorganized their machinery, with a minimum of capital outlay and inconvenience, owing to such power supplies being available.

We are not permitted to know specifically, or even in percentages, to what extent the output of munitions has risen during the past 12 months, but there is no doubt that an enormous increase has taken place. The Minister of

Munitions has, I believe, promised to enlighten us on this subject at an early date.

Everybody has realized the grave importance of keeping such works running throughout every available working hour, using every machine in the factory and every skilled or semi-skilled worker. Our gun, ordnance, and armament factories have drawn liberally for their extra power requirements on central station reserves in all industrial areas, and it is gratifying to note that modern power houses have, as a rule, been fairly well situated and equipped to meet the demands made on them.

The installation of large and economically operated units, such as turbo-generators, capable of dealing with heavy overloads has proved invaluable. The pressure of naval and merchant work has been enormous, and we on the Clyde are proud of the work turned out by the naval construction firms on the river.

Electricity, probably more in this branch of war activities than in any other, has played a great part in facilitating the rapid turning-out of work, and it has undoubtedly been to the advantage of the nation that in practically all the great shipbuilding centres all extra and urgent power requirements have been expeditiously met from local central stations.

Another industry which has required important and urgent power supply is that connected with the manufacture of motors, transport and Red Cross wagons—that highly important adjunct to the army in the field—and the rapidity with which our motor-car manufacturers have turned over and adapted their equipment to this service deserves every commendation.

There are many other branches of industry which at this time have required a quick and adequate supply of motive power ; for example, aircraft engineering, the manufacture and proofing of aeroplane and airship fabrics, floating mines and torpedoes, the manufacture of gun carriages, hospital equipment, etc.

In fact, there is no doubt that in the public electricity supply of the country the nation has at this critical period an asset of the first importance.

A very important matter in which the management of all generating stations is interested to-day, whether they be municipal or otherwise, is the cost of production. There are two items which enter very largely into such cost ; first, coal, and secondly labour.

Dealing with the first, we are at present almost entirely dependent upon coal as the prime source of power. I think that some sections of the country have sufficient water power to produce vast quantities of energy, but these are not yet developed, and the fact remains that coal is the principal item in the cost of generation.

Within the last year or two, the higher price of coal has increased very considerably the cost per unit generated, the cost of coal per ton having advanced by over 40 per cent. In fact, on comparing to-day's prices with those of 1911 and 1912 the increase is nearly 100 per cent. This varies in different districts, and the above percentages refer generally to the West of Scotland.

This increase, due very largely to conditions arising out of the war, was fortunately checked to some extent by the Government passing an Act which limits the price of coal to the consumer, and by recent legislation affecting the exportation of coal. We have to thank the local deputa-

tion who waited on the Government in regard to this matter and on whose representations Scotland was included in this legislation, which at one time was suggested should apply only to the South.

The remedy which power producers have is to insert a coal clause in their contracts with consumers, and this has been almost universal practice during the last few years. The terms of such a coal clause vary in different parts of Great Britain, the general practice, however, being to arrange as a basis a fixed price per ton delivered to the power house and to adjust the price per unit to the consumer in proportion to the increase or decrease of fuel costs per ton. In some cases a fixed price for a standard quality of coal at the pit mouth has been taken, the intention being to guard against an abnormal rise in the price of coal.

The second factor which enters so largely into the cost of production is labour. Most power producers have had to concede additional wages, generally in the way of a so-called war bonus to employees on account of the increased cost of living, and this is a factor which must be reckoned with at the end of the financial year.

Many electrical undertakings have not been interfered with to any very serious extent by the action of labour agitators; but a perusal of the daily newspaper reports of speeches made by labour leaders, some of whom have been manly enough to resign rather than submit to the claims of the so-called British workman, and the fervent words of, and the examples given by, the Minister of Munitions to a recent Trade Union Congress, together with the numerous instances reported of lost time, enforcement of restrictive rules and customs, these and many other incidents cannot fail to show the serious state of affairs that has existed in this country since the war began.

The labour agitators who advocate the line of action commonly known as "collective bargaining" must accept a large share of responsibility for this state of affairs. I feel sure that the intelligent members of the Labour Union and even the political labour parties of this country could not possibly give their sanction to much that has taken place within the last 15 months.

One knows and hears of men who have given up comfortable homes, left their families, and crossed thousands of miles of ocean to fight for their mother-country. What opinion can they possibly hold of the so-called British workman who not only acts in the way I have mentioned, but finds time to attend football matches, horse races, etc.? I am sure that all true patriots would have welcomed, either at the time war was declared, or shortly afterwards, a royal proclamation, putting every man, woman, and child in the country under martial law.

Another matter to which I should like to refer is the question of apprenticeship. The old method was that any lad wishing to learn a trade had to bind himself to a craftsman, who, in return for his labour during the apprenticeship period, say 5 to 7 years, undertook to keep him in food and lodging, and generally to teach him his trade, the law giving wide powers to the master. At the end of this period the lad became a journeyman. This system of apprenticeship produced an excellent type of workman, but, with the development of power and machinery, the system necessarily required amendment, and other methods have now been generally adopted.

The late Dugald Drummond made a great study of this subject, and, I believe, in conjunction with Mr. A. F. Yarrow and others, devised newer systems. To-day a lad can for a certain number of years be apprenticed to a firm in whose employ he must serve 6 months in each year, and for which service he receives a graduated scale of pay. He has the option of attending a technical school or college for the other 6 months of the year, or he can continue at his work and attend night classes. In this way he can learn both the practice and theory of engineering, and acquire some knowledge of the commercial side. The lad to-day who passes through his apprenticeship course and comes out of it with a reasonable knowledge of practical, theoretical, and commercial work, has—if it is in him—the making of a thoroughly successful man in almost any sphere.

I consider a great deal of good has been accomplished by the Students' Sections of this Institution, particularly under the able superintendence of the members who have given their valuable time and services to this work.

I should like to refer in a few words to the successful result of the employment of female labour, which has been necessitated by so great a number of our gallant fellows having joined the Colours.

In our offices to-day I think that women should be employed wherever possible to replace all men of military age. In many cases this is not possible, but wherever it can be done, it should be carried out. Women have shown capability in many of our munition factories, railways, and in numerous other occupations hitherto filled by men, and I am sure that we in Glasgow appreciate the splendid work done by women conductors on our tramcars. The work of the Scottish Committee on substitutionary labour deserves our fullest support.

Much speculation has been indulged in as to how the electrical industry as a whole is going to be affected when the war is over. It is very difficult to forecast what may happen, but a few points occur to me which I think are worthy of consideration.

It is almost certain that there will be a reduction in the power supply required for munition work, a great deal of which must necessarily be of a temporary character, many contracts having been made for the duration of the war only. It will take some time to re-organize industrial works which are temporarily equipped for this class of work, and to restore their plant to normal industrial capacity.

On the other hand, it is quite possible that a great many manufacturers will find new markets for their products, both at home and abroad.

During the period of the war our shipyards have been almost exclusively engaged on war material. A great many ships have been rendered useless for their original purposes, through being stripped of their fittings and converted into armed cruisers, transports, etc. The shortage of merchant ships consequent on German submarine activities must to some extent be made up. It is therefore reasonable to expect that shipbuilders and a great many engineering concerns which depend on the subsidiary work in connection with both naval and mercantile ship-building and ship repairing will be exceedingly busy.

The restrictions placed on the export of coal will be withdrawn, and the output of the collieries should be consequently increased.

Opportunities will be afforded to British manufacturers to obtain a firm footing all over the world in markets which have hitherto been entirely in the hands of the Germans, and, if these opportunities are grasped, an increase in the number of industrial factories may be looked for.

Naturally, money to finance new projects will be both scarce and dear, but, making allowance for this, we should be in a better position than our enemies or allies, whose countries have been devastated and many of their most important factories destroyed. This is a subject which should engage the most thorough consideration and careful attention of the personnel of the electrical industry in common with all other British manufacturers. We must face the future in a spirit of calm optimism; and, if we must "wait and see," let our waiting be watchful, and with Britain fully "waked up" the recapture of their former world trade by the Germans should be a "negative possibility."

In concluding these remarks, I should like to say a word or two about the great necessity for increasing the number of men in our Army and our Navy. We have, in the latter, men and ships scattered all over the world, ready for any and all contingencies. Our armies have also been widely distributed. Our colonies are not only able to look after themselves but have placed the best of their citizens at the disposal of the mother country. Naturally I am very proud of the part played by my native country, Canada, in this war. And now we have to send armies and reserves against countries which were supposed to be allies or at least neutral on the outbreak of war.

Those of us who are unable to go to the front must do our share at home. I have referred to the men and women working in overalls, but the men and women who cannot take an active part in this war must do their share by economizing in everything possible and by subscribing every penny they can save or have saved, rather than see the efforts of our brave soldiers and sailors rendered abortive.

## ARMATURE COPPER LOSSES IN ROTARY CONVERTERS AND DOUBLE-CURRENT GENERATORS.

By LAURENCE H. A. CARR, M.Sc. Tech., Associate Member.

(Paper received 10 June, 1915.)

### SUMMARY.

This paper deals with the calculation of the copper losses in an armature carrying both continuous and sinusoidal current, and conversely the calculation of the output of such a double-current machine (as for instance a rotary converter) in terms of the output as a continuous-current machine for equal total armature copper losses.

If any specific conductor in a rotary-converter armature be considered, it is evident that the resultant current which it carries is the sum of two currents, one being sinusoidal, the other being constant over a half-cycle and then reversing to an equal and opposite value for the next half-cycle.

For a conductor midway between the slip-ring tappings, and assuming unity power factor, the continuous current reverses when the alternating current is passing through its zero value.

In a rotary converter the alternating and continuous currents are in opposite senses, since one tends to motor the machine while the other is being generated, so that the value of the current at any moment during the half-cycle may be represented by the expression

$$I_M \sin \theta - I_0 \quad \dots \dots \dots (1)$$

where  $I_M$  is the maximum value of the alternating current in terms of the continuous current.

The copper loss for an infinitely short time (which may conveniently be measured in terms of  $\theta$ ) is then

$$(I_M \sin \theta - I_0)^2 d\theta$$

and the total watts lost as heat per half-cycle may be obtained by integrating this expression over half a cycle, i.e. between the limits of  $\theta = \pi$  and  $\theta$ .

Then

$$\begin{aligned} h &= \int_{\theta=\pi}^{\theta} (I_M \sin \theta - I_0)^2 d\theta \\ &= \int_{\theta=\pi}^{\theta} \{ I_M^2 \sin^2 \theta - 2 I_M I_0 \sin \theta + I_0^2 \} d\theta \\ &= \left[ I_M^2 \left( \frac{1}{2} \theta - \frac{1}{4} \sin 2\theta \right) + 2 I_M I_0 \cos \theta + \theta \right]_{\theta=\pi}^{\theta} \\ &= I_M^2 \left[ \theta - \frac{(\theta - \pi)}{2} - \frac{1}{4} \{ \sin 2\theta - \sin (2\theta - 2\pi) \} \right] \\ &\quad + 2 I_M I_0 \{ \cos \theta - \cos (\theta - \pi) \} + \theta - (\theta - \pi) \\ &= I_M^2 \pi / 2 + 4 I_M I_0 \cos \theta + \pi \\ &= \pi \left\{ I_M^2 / 2 + 1 \right\} + 4 I_M I_0 \cos \theta \quad \dots \dots \dots (2) \end{aligned}$$

where  $h$  is the total watts lost per half-cycle for the given conductor.  $\theta$  is of course equal to  $\pi$  in the above simple case, but, as will be shown later, it has other values for other conditions, hence it is preferable to keep it in the indeterminate form  $\theta$ .

Consider now other portions of the armature. The current may still be represented by the expression  $(I_M \sin \theta - I_0)$  over the half-cycle between the reversals of the continuous current, but these reversals no longer take place at the zero values of the alternating-current wave; therefore the limits of integration are no longer 0 and  $\pi$ .

If the rotary converter has  $n$  slip-rings, the winding (considered as a 2-pole winding throughout) is divided into  $n$  sections, each subtending an angle of  $2\pi/n$  on the armature. The leading end of such a section of the winding then comes under the brush when it has a phase angle of  $-\pi/n$ , and again when it has a phase angle of  $\pi - \pi/n$ , these values then being the limits of integration for that element of the winding, and  $\theta = \pi - \pi/n$ . Similarly for the trailing end of the winding  $\theta = \pi + \pi/n$ , and the value of  $\theta$  varies uniformly between these two values over that section of the winding between the slip-rings.

If the alternating current is lagging in phase by the angle  $\phi$ , the elements of the winding pass through the changes mentioned above, while the current is in phase earlier still by the angle  $\phi$ ; that is  $\theta$  varies from  $(\pi - \phi) - \pi/n$  to  $(\pi - \phi) + \pi/n$  over the section of the winding between the slip-rings.

Consider now, as a basis of comparison, the effect of the continuous current alone.

The summation of the expression (current)<sup>2</sup>  $d\theta$  over half a cycle, or through an angle  $\pi$ , is obviously equal to  $\pi$ , where the continuous current in each circuit is 1.0, as taken before. This of course corresponds to an output current of 2.0.

From the above, the heating of any given element of the armature can be compared with its heating by continuous current alone.

The heating or copper loss over a small element of the armature subtending an angle  $d\theta$  at the centre is then, from Equation (2),

$$h d\theta = \frac{1}{2} \pi \left( \frac{1}{2} I_M + 1 \right) + 4 I_M \cos \theta \} d\theta.$$

The total heating over one section of the armature winding between the slip-rings is then the summation of the above value for  $h$  between the following limits:—

$(\pi - \phi) - \pi/n$ , which may conveniently be called  $\alpha$ , and  $(\pi - \phi) + \pi/n$ , which may conveniently be called  $\beta$ .

Since there are  $n$  such sections on the armature, the total loss  $H$  may be written:—

$$\begin{aligned} H &= n \int_{\alpha}^{\beta} \left\{ \pi \left( \frac{1}{2} I_M + 1 \right) + 4 I_M \cos \theta \right\} d\theta \\ &= n \left[ \pi \theta \left( \frac{1}{2} I_M + 1 \right) + 4 I_M \sin \theta \right]_{\alpha}^{\beta} \\ &= n \left[ \pi (\beta - \alpha) \left( \frac{1}{2} I_M + 1 \right) + 4 I_M (\sin \beta - \sin \alpha) \right]. \quad (3) \end{aligned}$$

Two trigonometrical simplifications are possible in this formula, namely:—

$$n(\beta - \alpha) = n \left[ (\pi - \phi) + \pi/n \right] - \left[ (\pi - \phi) - \pi/n \right] = 2\pi$$

and

$$\begin{aligned} \sin \beta - \sin \alpha &= \sin \left\{ (\pi - \phi) + \pi/n \right\} - \sin \left\{ (\pi - \phi) - \pi/n \right\} \\ &= 2 \cos (\pi - \phi) \sin (\pi/n) \\ &= -2 \cos \phi \sin (\pi/n). \end{aligned}$$

The resultant equation therefore becomes

$$H = 2\pi^2 \left( \frac{1}{2} I_M + 1 \right) - 8 I_M n \cos \phi \sin (\pi/n). \quad (4)$$

The corresponding loss as a continuous-current machine with the same continuous current is the loss per element  $\pi$  summed over the whole circumference, i.e.  $2\pi^2$ .

Dividing the value of  $H$  in Equation (4) by  $2\pi^2$  and replacing  $I_M$  by  $\sqrt{2} I$ , where  $I$  is the virtual value of the alternating current, the equation becomes

$$W = H/(2\pi^2) = (I^2 + 1) - 0.573 I n \cos \phi \sin (\pi/n). \quad (5)$$

where  $I$  is the virtual value of the alternating current in the armature winding (not in the mains) in terms of the continuous current in the winding, and  $W$  is the number of watts lost in terms of the watts that would be lost ( $I^2 R$  loss) if the machine were acting as a plain continuous-current generator with the same current on the continuous side,  $n$  being the number of slip-rings.

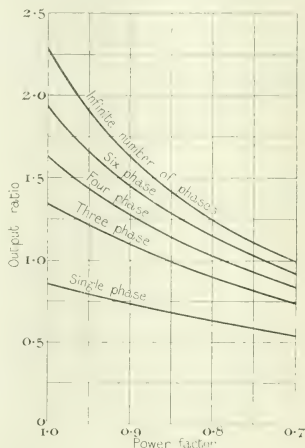


FIG. 1.

Here it may be noted that  $\cos \phi$  is the only form in which  $\phi$  enters into the equation; and since  $\cos \phi = \cos (-\phi)$ , it is immaterial whether  $\phi$ , and hence the current, is leading or lagging. Further, the negative sign indicates that the two currents (C.C. and A.C.) flow in opposite directions. If they are in the same direction, as in a double-current generator, the sign must be changed to +, or the value of  $\phi$  may be considered to be increased by  $\pi$ , which gives the same result.

For such a machine also it is more convenient to take the virtual value of the alternating current. We get therefore for a double-current generator

$$W = (I^2 + 1) + 0.573 I n \cos \phi \sin (\pi/n). \quad (6)$$

where  $I$  is the virtual value of the alternating current in the armature winding (not in the mains) in terms of the continuous current in the winding, and  $W$  is the number of watts lost in terms of the watts that would be lost if the continuous current alone were acting.

Conversely, it may be taken that given the value of  $I$ ,  $n$ , and  $\phi$  in Equations (5) and (6), the output obtainable with the same total armature loss is  $\sqrt{1/W}$  times the output obtainable from the same armature as a plain continuous-current generator, both outputs being measured on the continuous-current side. Returning to Equation (5), which is a general equation for all values of  $I$ , it is evident that in a machine acting purely as a rotary converter the factor  $I$  is dependent on the factors  $n$  and  $\phi$ , so that further simplification is possible.

The maximum voltage on the alternating-current side of a rotary converter is  $E \sin(\pi/n)$ , where  $E$  is the voltage on the continuous-current side. Hence the virtual alternating electromotive force is

$$0.707 E \sin(\pi/n).$$

For an efficiency of 100 per cent the energy is the same on both the continuous and alternating sides.

The energy on the alternating side

$$= n \times I \times \text{alternating voltage} \times \cos \phi,$$

and the energy on the continuous side

$$= 2 E \times \text{continuous current},$$

the currents in each case being measured in the windings.

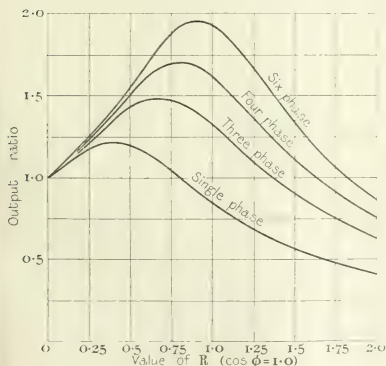


FIG. 2.

Therefore the alternating current  $I$  in Equation (5) is, in terms of the continuous current,

$$\begin{aligned} &= \frac{2E}{n \times 0.707 E \sin(\pi/n) \times \cos \phi} \\ &= \frac{2.828}{n \cos \phi \sin(\pi/n)} \end{aligned} \quad (7)$$

Replacing  $I$  in Equation (5) by this value, the following result is obtained:—

$$\begin{aligned} W &= \left( \frac{2.828}{n \cos \phi \sin(\pi/n)} \right)^2 + 1 - 1.62 \\ &= \left( \frac{2.828}{n \cos \phi \sin(\pi/n)} \right)^2 - 0.62 \end{aligned} \quad (8)$$

Filling in the value for  $n$  (for 1, 3, 4, and 6 phases  $n=2, 3, 4$ , and 6 respectively) the following equations are obtained:—

$$\text{For single phase } W = \frac{2}{\cos^2 \phi} - 0.62 \quad (9a)$$

$$\text{For three phase } W = \frac{1.185}{\cos^2 \phi} - 0.62 \quad (9b)$$

$$\text{For four phase } W = \frac{1.0}{\cos^2 \phi} - 0.62 \quad (9c)$$

$$\text{For six phase } W = \frac{0.888}{\cos^2 \phi} - 0.62 \quad (9d)$$

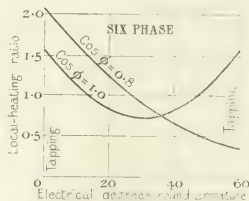
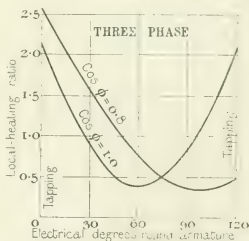
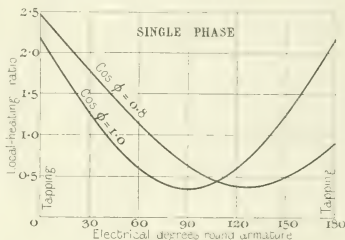


FIG. 3.

For an infinite number of phases  $\pi/n$  is extremely small, and  $\sin(\pi/n) = \pi/n$ , hence  $n \sin(\pi/n) = \pi$ , and

$$W = \frac{0.81}{\cos^2 \phi} - 0.62 \quad (10)$$

The above are the equations for plain rotary converters with no loss in conversion,  $W$  being the copper loss in terms of the copper loss that would occur if the machine were giving the same current on the continuous-current side as a plain continuous-current generator. The last equation shows that there is no great advantage to be gained by increasing the number of phases above six.

Conversely the value of  $\sqrt{1/W}$  gives the output obtainable from a rotary converter for the same total armature copper loss, in terms of the continuous-current output which would give that copper loss, both outputs being measured on the continuous-current side (see Fig. 1).

In certain cases it may happen that the rotary converter is doing mechanical work (either positive or negative) in addition to its converting functions, as for example when a rotary converter has coupled to it a booster, which may be either raising the volts (boosting) or lowering the volts (motoring). In this case either Equation (5) may be used, or if by  $R$  we denote the ratio of the actual alternating current on the rotary-converter slip-rings to the current for one-to-one power conversion, Equations (9a), (9b), (9c), and (9d) become

$$\text{Single phase } W = \frac{2R}{\cos \phi} + 1 - 1.02R \quad \dots (10a)$$

$$\text{Three phase } W = \frac{1.185R}{\cos \phi} + 1 - 1.02R \quad \dots (10b)$$

$$\text{Four phase } W = \frac{R'}{\cos \phi} + 1 - 1.02R \quad \dots (10c)$$

$$\text{Six phase } W = \frac{0.888R}{\cos \phi} + 1 - 1.02R \quad \dots (10d)$$

These figures are easily obtained by substituting  $1/R$  for  $I$  in Equation (5), and if  $R$  be taken negative, the conditions for a double-current generator are obtained—this being an alternative form to Equation (6), with which it agrees.

Curves showing the values of  $\sqrt{1/W}$  obtained are given in Fig. 2, and while  $R = 1.0$  only applies to the theoretical condition of an efficiency of 100 per cent, these curves show the correction to be applied when the machine is motoring from the alternating-current end ( $R$  slightly greater than unity) or from the continuous-current end ( $R$  slightly less than unity).

From these curves it is noticeable that to keep the rotary-converter losses down, and hence the output up, it pays to keep the alternating current less than the simple transformation ratio. Thus if the machine is supplied with an

alternating-current booster in series with the armature, it pays to let the booster reduce the alternating voltage, i.e. to motor (if the set is motoring from the alternating-current side).

The local distribution of the heating around the armature between the slip-ringappings can be calculated from Equation (2),  $\theta$  being varied between its limits of  $(\pi - \phi) - \pi/2$  and  $(\pi - \phi) + \pi/2$ .

Fig. 3 shows some typical curves for converters with a one-to-one power-transformation ratio.

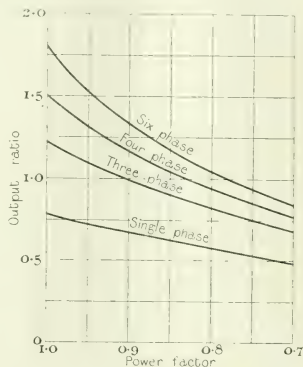


FIG. 4.

The actual margin to be allowed in the output of the rotary converter depends of course on the ratio of the iron losses to the copper losses, and on the quality of the ventilation, etc. It must be therefore left to the judgment of the individual designer. As a suggestion for practical use, the curves shown in Fig. 4 have been plotted. These allow, first, for the alternating current to be increased 5 per cent above the theoretical value ( $R = 1.05$ ) in order to allow for driving the machine, and secondly, a margin of 5 per cent in output below the value thus obtained in order to allow for unequal armature heating.

## WESTERN LOCAL SECTION: CHAIRMAN'S ADDRESS.

By DAVID E. ROBERTS, Member.

*(Address delivered 25 October, 1915.)*

At the beginning of last Session I had the honour of addressing members of this Local Section upon the conditions that are likely to affect our industries when this great war is over.\* In any review of the past year, the war must continue to be the outstanding topic. We are now learning to the full the gigantic nature of the enemy's resources, and we are beginning to realize what an immense and continuous effort must be put forward in order to succeed.

The organizing of the nation, the bringing into line of all its industries, the active co-operation of all engineering establishments in the production of the Government's needs, will constitute some day a wonderful story, and will prove again that a great characteristic of the British race is its power of adaptability to circumstances, its power of rising to the occasion when really in earnest. It is not true to say that this faculty of adaptability is habitual, or is even followed extensively in ordinary commercial life, but it is true that on certain rare occasions in our history, in times of great need when the country has been brought face to face with critical danger, this characteristic has been developed to the full. It must not be forgotten, however, that the power of adaptability is really relative; that is to say, its extent depends upon the resources that are available.

I cannot help thinking that when, later on, the present position is studied in its proper perspective and clear of all bewildering conditions, it will be seen that the ability of manufacturers to come so fully to the aid of the Government—the organizing, in fact, of the whole country into one huge munition factory—is largely attributable to the resources available as a result of the great development of certain industries in recent years. Of these, electrical engineering furnishes one important example. From personal observation, however, made in various parts of the country during this year, in my opinion the motor-vehicle industry possibly has effected even a greater influence than any other individual trade on the present position. It is perhaps invidious thus to single out any one particular industry when all have done such excellent service. Nevertheless, I believe it will one day be realized that the immense development of the motor industry in this country has providentially occurred just at the correct moment, and has provided us with, in addition to vast supplies of useful motor vehicles, a combination of conditions as regards factories, machines, repetition processes, and trained labour, which has been invaluable in the finishing of munitions.

In the rapid building up and extension of the many new munition factories, electrical engineering has, of course, played a very important part. Indeed, it is questionable whether it would have been possible by any other means to install so rapidly and to operate the

innumerable additional machines that have been set going. The equipping of workshops to-day with motor-driven modern tools must be looked upon as an exceedingly expeditious and, indeed, also a comparatively simple matter, when one remembers the methods of say only 20 years ago.

With regard to our future prospects, it is not to be expected that trade will right itself immediately peace is restored. That is too much to hope for after what will be more or less a war of exhaustion, and it will be doubtless some years before we reach normal times again. It is expected, due to our more wholesome economic conditions, and to the great number of our old and firmly established industries, that we shall recuperate more quickly than our enemies. It is also to be hoped that the vast additions of plant that have been now installed at enormous cost for special war work will be later turned to useful account in new and re-arranged situations suited to the requirements of the time, and that the expenditure on them will therefore become fully productive.

Future labour conditions and difficulties are largely matters of conjecture. It is quite likely that objections will be offered to the removal of privileges now temporarily enjoyed by the men, and it is not quite easy on the other hand to see how unskilled labour now being trained is going to be entirely discarded. It must also not be overlooked that besides the casualties, large numbers of men accustomed in the past to indoor occupation will not readily return to their old employment after their military training. Many such men will probably seek by emigration the freer and more open life offered by Canada and Australia.

Several other changes in our everyday life are also growing up, which in my opinion will in part continue. As an example, take the rapidly extending employment of young women in our offices as clerks, on our railways and tramways as ticket collectors, and in many other occupations of a light character, where they are proving their fitness for such work. Altogether it is exceedingly difficult to prophesy, with even reasonable correctness, in regard to the labour problem, since conditions will be so complex and their effects so far-reaching.

The future looks at present cloudy and uncertain, and the organization of the country must be carried out even more completely to meet and overcome our immense difficulties; and, most important of all, we shall have to be exceedingly careful to keep our differences buried and to prevent anything in the nature of disunion taking place amongst ourselves.

We may take much hope from the assurance that our Navy is supreme and commands the sea. It would appear as though this factor must in the long run bring about the enemy's downfall if we can hold him in other directions, as no nation can live long without commerce.

\* *Journal I.E.E.*, vol. 53, p. 471, 1915.

Our achievements must, I feel certain, make us all more proud than ever of being British, and further than that, of being British engineers, for it has been truly said that this is really an engineers' war.

We have much to be thankful for. First, that the time of the struggle was not postponed; secondly, in having a powerful combination of Allies; and, again, it should not be overlooked that the South African war was perhaps, after all, a blessing in disguise, by providing us for this crucial test with timely experience in the organization and control of military operations on a large scale away from home.

The horrors of the campaign and the toll of life entailed are terrible, and there will be hardly a family in the land

that will entirely escape suffering, but the sacrifice will not be in vain. We entered the fight to uphold the rights of the weaker nations, and have conducted the campaign in accordance with the established usages of warfare, and we have therefore nothing with which to reproach ourselves. We shall have undergone a great, though drastic, cure, and national life will be in a healthier state.

The practice of helping each other, which is now so universal, will, it is hoped, remain a habit, and in a vigorous and revived condition we shall go forward to compete for our share of the world's trade and retain with dignity and respect our commanding position among the great nations.

## THE PRODUCTION AND PROPERTIES OF ELECTROLYTIC COPPER.

### MANCHESTER LOCAL SECTION: CHAIRMAN'S ADDRESS.

By B. WELBURN, Member.

(Address delivered 10 November, 1915.)

#### SYNOPSIS.

Sources and production.  
Smelting, etc., of copper ores.  
Rolling and wire drawing.  
Annealing.  
Joining of wires.  
Micro-photographs.  
British standard for copper conductors.  
Testing and definition of hard-drawn copper.  
Elasticity.  
Modulus of elasticity.  
Tensile strength.  
Effect of temperature on the strength of hard-drawn copper.

#### SOURCES AND PRODUCTION.

The world's output of copper in normal times is about one million English tons per annum, the highest production recorded being that of approximately 1,006,000 tons for the year 1912. Of this total, the United States alone produced 55 per cent (against only 572 tons in 1850), the whole of North America 66 per cent, and North and South America together 73 per cent. Japan is the next biggest producer with 65,500 tons. Spain and Portugal gave 59,000 tons, Russia 33,000 tons, Australasia 47,000 tons, while the combined production of Germany, Hungary, Turkey, and Bulgaria is about 35,000 tons.

The British Isles now produce only 300 to 400 tons, whereas the native production was 15,968 tons in 1860.

The world's production in 1850 was 52,400 tons. It had reached 334,565 tons in 1895, and this had trebled by 1912. In the same period the output of the British Empire was more than quadrupled, namely from 23,495 to 99,440 tons.

#### SMELTING, ETC., OF COPPER ORES.

Copper is nearly always associated with gold and silver, which can be electrolytically separated from it and are now recovered instead of being lost, as was usually the case until electrical methods were available. About 70 per cent of the world's output of copper is refined electrically; and from the 461,583 tons refined in the United States in 1907, 13,995,436 ounces of silver and 272,150 ounces of gold were recovered by electrolytic separation.

In order to get rid of part of their sulphur, most of the ores have to be calcined before smelting, and this is done in mechanical calciners. After partial calcination the ore is smelted (usually in a cupola furnace) to extract the earthy matter and to concentrate the copper, etc., with part of the sulphur and iron into a matte. This matte will contain from 45 to 50 per cent of copper; it is then transferred to a Bessemer converter which raises the proportion to from 97 to 99 per cent including the gold and silver contents, and is the result of treating ores which have sometimes only 3 to 4 per cent of copper originally. The copper is run from the converter into slabs measuring about 18 in.  $\times$  28 in.  $\times$  3 in., which are then transferred to the refinery, where they are again melted for 24 hours for further purification in a reverberatory furnace with a capacity of 150 to 200 tons of copper. The copper from this furnace is run into moulds to form the cast anodes, which are usually 36 in.  $\times$  36 in.  $\times$  1½ in. thick and weigh 500 lb. each.

Under good conditions in works in the United States the cost of converting a 50 per cent matte to metallic copper is about one-third of a penny per lb. of refined copper.

Most works employ the multiple system in which anodes of cast copper and cathodes of electrically-deposited copper strippings 36 in.  $\times$  36 in.  $\times$  1/32 in. thick are hung in lead-lined vats. The space between the electrodes is 1½ to 2 inches, and the pressure employed is about 0.3 volt for every pair of electrodes in series. The electrolyte is an acidulated solution of cupric sulphate and contains 1½ to 2 lb. of  $\text{CuSO}_4$  and from 5 to 10 oz. of  $\text{H}_2\text{SO}_4$  per gallon of water, and is maintained at a temperature of 130° F. The current density is usually 7½ to 12 amperes and should not exceed 18 amperes per square foot of anode surface, as it has been found by experience that the mechanical properties of the metal depend on the current density used. With this latter density a high temperature and rapid circulation of the electrolyte must be maintained.

In practice, anodes 1½ in. thick decrease in thickness in 10 days to ½ in. thick, and pure electrolytic copper is deposited on the cathodes until they are just over ½ in. thick, while the precious metals settle as slime at the bottom of the vat. The ½ in. thickness of anode which is left is returned to anode furnaces for re-melting and further casting.

Theoretically, with a 100 per cent current efficiency and 0.3 volt between electrodes, 1 lb. of copper should require about 0.115 kilowatt-hours, but in practice the total con-

sumption required for refining and for power and lighting in the largest works is 0.14 to 0.15 kilowatt-hour. The overall cost of the electrolytic refining of copper is not published by the refiners, but it is believed to vary from a farthing to ¾ d. per lb. The finished cathodes are melted down, blown with air, poled, and then cast into wire bars, the average weight of which in England is 140 lb. and in the United States 220 lb.; but if required by the wire manufacturers special bars up to 800 lb. in weight can be produced.

#### ROLLING AND WIRE DRAWING.

My task is rendered easier to-night from the fact that I am only dealing with copper as used for the transmission of electricity. For this purpose two varieties only are required:—

- (1) Hard-drawn copper; (2) Soft or annealed copper.

Busbars for switchboard work may either be hard-drawn or annealed as required.

The actual manufacture of wire from wire-bars is a straightforward process, and wires can be successfully drawn from 1 mil in diameter of very considerable lengths

TABLE I.  
*Drawn Specimen (Mr. T. Bolton).*

Diameter	Tensile Strength	Elongation in 10 in.
In.	Tons per sq. in.	Per cent
0.500	23.68	3.8
0.404	24.38	3.2
0.432	24.71	3.0
0.400	25.62	3.0
0.348	27.34	2.8
0.300	28.30	2.6
0.250	27.60	2.8

sary to remove the scale by acid pickling and by washing. The removed scale is readily convertible back to copper by an electrolytic process. The clean coils are taken to the wire-drawing machines in which the rod is drawn into wire by means of chilled iron and/or diamond dies according

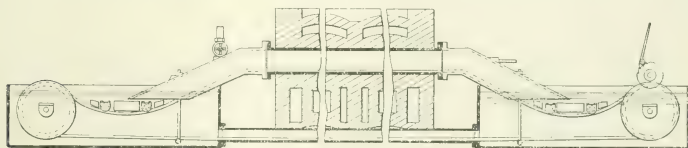


FIG. 1.—Annealing Furnace.

to the size. Wires of No. 17 S.W.G. and under are usually drawn through diamond dies only.

The number of dies or "holes" through which the wire is drawn down to the required diameter depends on whether the wire is to be used "hard" or "soft" and, if the former, on what tensile strength and other mechanical properties are needed. Generally speaking, the greater the number of holes or dies the higher is the resultant tensile strength. This is illustrated in Table I, which also indicates why stranded conductors should be used on overhead transmission lines in preference to solid wires.

#### ANNEALING.

If soft copper is needed, the hard-drawn copper can be treated in a number of ways. The modern process most used for annealing copper and other non-ferrous metals is that known as the "Bates and Peard," or some variation of it (see Fig. 1). The system consists essentially of a cast-iron retort which is heated externally and sealed by water at both ends to prevent the entry of air through the descending mouthpieces. The retort is filled with water vapour under pressure at a temperature of about 800° F. for small wires and 1,100° F. for larger wires, and the

copper which is to be annealed is carried slowly through the heated tube by means of an endless conveyer. When the copper comes out of the retort, it is found to be perfectly annealed and to be as bright in colour as it was before treatment, while there has been no loss of weight. The heat remaining in the coils of wire is sufficient to cause the water from the seals to evaporate and to leave quite dry wire, which is then ready for stranding and insulating.

#### JOINING OF WIRES.

Where long lengths of wire are required, it is frequently necessary to join wires together during manufacture.

In the smaller sizes such as are used in the construction of insulated cables, this may be done conveniently and economically by the use of electrical butt-welders, and these joints will stand further drawing through dies.

For trolley wires, some engineers prefer that copper wire-bars of suitable weight should be used to ensure getting the length required without any joints. An alternative to this method is to join the rolled rods (from which the wire is to be drawn) by means of scarfed joints, which are brazed together with silver as the solder, and extensive experience of this method shows that it is entirely successful. Both this and the electrically-welded joint referred to earlier will stand drawing down through the dies, and, in the finished wire, the joint cannot usually be detected by the eye nor is its tensile strength any less than that of the rest of the wire. In fact it is usually higher.

MICRO-PHOTOGRAPHS OF COPPER SECTIONS (Each specimen has been magnified 165 times).

Fig. 2.—Copper growth on cathode as deposited. This clearly shows the irregular polygon crystal boundaries.



FIG. 2.

The dotted line is formed by  $\text{CuSO}_4$  which has been trapped from the electrolyte.

Fig. 3.—Wire bar as cast from the cathode. This again shows the irregular polygon crystal formation. The thick

dark boundary lines are due to the presence of copper oxide, the formation of which is inevitable when the cathodes are being smelted. Most of it is removed by "poling," i.e. stirring the molten copper with green wood.

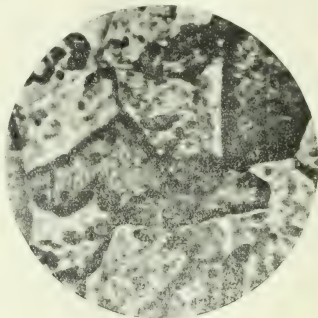


FIG. 3.

If the remaining quantity of oxide present exceeds a critical value, the result will be both red-short and cold-short metal. If it be less than the value, the metal will be cold-short. The critical quantity is usually about 0.02 per cent.

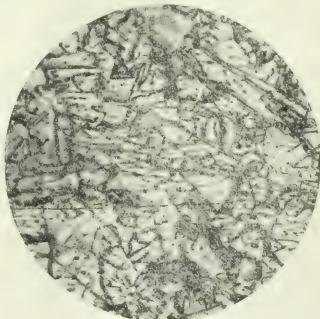


FIG. 4.

Fig. 4.—Annealed copper showing the crystals after work has been done on the copper. The density of the crystals will be noted, as compared with Fig. 3. The weight of copper in this state is 0.321 lb. per cubic inch.

## BRITISH STANDARD FOR COPPER CONDUCTORS.

The first attempt to standardize copper conductors was made by an Institution Committee whose Report was published in the *Journal*.\*

The standard at present in use is the one issued by the Engineering Standards Committee (No. 7, revised March 1910), but it is understood that this is under revision. It is certainly needed in view of Publication No. 28† of the International Electrotechnical Commission, which publication has already been adopted in the new Standardization Rules of the American Institute of Electrical Engineers, dated 1 July, 1915, as follows:—

(1) At the temperature of 20° C. the resistance of a wire of standard annealed copper 1 metre in length and of a uniform section of 1 square millimetre is 1/58 ohm = 0.0172414 ohm (20° C. = 68° F.).

(2) At a temperature of 20° C. the density of standard annealed copper is 8.89 grammes per cubic centimetre (55.4985 lb. per cubic foot).

(3) At a temperature of 20° C. the "constant mass" temperature coefficient of resistance of standard annealed copper measured between two potential points rigidly fixed to the wire is 0.00393 = 1/254.453 per degree C. (0.00218333 = 1/458.016 per degree F.).

(4) As a consequence, it follows from (1) and (2) that, at a temperature of 20° C., the resistance of a wire of standard annealed copper of uniform section, one metre in length and weighing one gramme, is  $1/58 \times 8.89 = 0.15328$  ohm.

Paragraphs (1) and (4) define "volume resistivity" and "mass resistivity" respectively. These may be expressed in other units as follows:—Volume resistivity = 1.7241 microhm-cm. (microhms in a cm. cube) at 20° C., = 0.67879 microhm-inch at 20° C.; and "Mass Resistivity" = 875.20 ohms (mile, lb.) at 20° C.

In the interests of uniformity, it is to be hoped that the Engineering Standards Committee will adopt the above standards and will further provide that:—

(5) The resistance of hard-drawn copper shall be considered 2.7 per cent greater than that of annealed copper of the same size at the same temperature (i.e. 20° C. or 68° F.).

(6) The legal standard wire gauge as fixed by Order in Council, dated 23 August, 1883, shall be adopted as the standard gauge as in the existing standards.

(7) Minimum values of tensile strength, extension, and limit of proportionality shall be given for each gauge of hard-drawn wire. These points will be discussed more fully later.

In the meantime, it should be noted that the Engineering Standards Committee defines hard-drawn copper wire as wire which does not elongate more than 4 per cent on a gauge length of 10 inches when broken by tension, and that the standard resistance for it is just 2 per cent higher than that for annealed wire at 60° F. (15.6° C.).

It may also be noted that the Board of Trade's existing "Regulations for Overhead Lines" require that the elongation of hard-drawn copper wire shall not be less than 2 per cent in a length of 10 inches, so that wires for such lines naturally fall between elongation limits of 2 and 4 per cent.

The British Engineering Standard for trolley wire is contained in Report No. 23, issued in August 1905, but it needs revision in view of the subsequent experience gained in the manufacture of such wires and of the common use of grooved sections of trolley wires.

## TESTING AND DEFINITION OF HARD-DRAWN COPPER.

The testing of annealed copper conductors is very simple and is confined to gauging the wires with a micrometer gauge, measuring the ohmic resistance and, sometimes, to the weighing of samples or coils. In the case of hard-drawn copper additional tests are necessary to determine:—(1) Tensile strength. (2) Extension as a test of hardness. (3) Limit of proportionality (elastic limit). (4) Absence of brittleness.

Tests (1), (2), and (3) are usually made simultaneously on a specimen which is exactly 10 in. long between the grips of a suitable testing machine. Modern testing machines are arranged so that autographic records of the extension of the wire may be taken which are sufficiently accurate for commercial work. If, however, exact extension measurements are needed, then they must be made carefully by an experienced worker with an extensometer. In practice it is found that the actual tensile strength increases proportionately to the diameter, and not to the sectional area as one would expect, although the tensile strength in tons per square inch increases with a decrease of diameter. After analysing a number of tests made by Mr. Thomas Bolton, Mr. A. P. Trotter found that the tensile strength could be expressed as follows:—

$$T = a - bD.$$

Mr. D. R. Pye and other investigators have found from a large number of tests the value of (*a*) to be approximately 30, and that of (*b*) to be 20 on all sizes of conductors up to 0.5 in. diameter.

It is not, however, sufficient to define the strength of the wire; it is also necessary to have some check on its hardness and absence of brittleness by ascertaining that it does not fall below a stated extension per cent. Tests on wires from 0.075 to 0.5 in. diameter show that the minimum extension can be expressed by

$$E = 5 D.$$

On these results Mr. Pye has suggested\* the following as the basis of a satisfactory definition of hard-drawn copper: "Hard-drawn copper, when in the form of circular wires, shall have a tensile strength not less than that given by the formula

$$T = 30 - 20 D,$$

"and an extension per cent on a marked 10 in. length, including point of fracture, of not less than that given by the formula

$$e = 5 \times D,$$

"where in the foregoing formulae

*T* = tensile strength in tons per square inch of original section,

*e* = extension per cent,

*D* = diameter of the circular rod in inches."

\* *Journal of the Institute of Metals*, vol. 6, p. 105, 1911.

\* *Journal I.E.E.*, vol. 20, p. 160, 1900.

† International Standard of Resistance for Copper, March 1914.

An examination of the standard figures prepared by the Wire Committee of the American Society for Testing Materials (1009) for wires ranging from 0.04 to 0.4 in. diameter shows that they agree closely with the above

TABLE 2.—*Hard-drawn Copper.*

Gauge in in.	Sample No.	Pyc's Formula		Practical Results	
		Breaking Stress in Tons per sq. in.	Extension per cent in 10 in.	Breaking Stress in Tons per sq. in.	Extension per cent in 10 in.
0.380	1	22.40	1.9	24.5	3.2
"	2	"	"	25.0	2.2
"	3	"	"	24.2	2.4
0.300	1	24.00	1.5	25.25	2.5
"	2	"	"	25.10	2.5
"	3	"	"	25.15	2.5
0.224	1	25.52	1.12	26.37	2.25
"	2	"	"	26.60	2.20
"	3	"	"	26.60	2.0
0.158	1	26.84	0.70	27.75	1.5
"	2	"	"	27.75	1.5
"	3	"	"	28.0	1.25
0.112	1	27.76	0.50	29.0	0.50
"	2	"	"	30.0	1.00
"	3	"	"	30.0	0.75
0.0791	1	28.42	0.395	31.34	0.50
"	2	"	"	31.40	0.40
"	3	"	"	31.33	0.41

specification for strength, while the minimum extension figures agree closely with the formula

$$e = 4\sqrt{D},$$

The Engineering Standards Committee might, therefore, consider the adoption of Mr. Pyc's specification on the grounds that—

(a) It calls for a high standard which can easily be obtained by the leading manufacturers throughout the world;

(b) Tables of the minimum tensile strength and extension per cent can be prepared for use for all the usual sizes of wires; and

(c) It is easily applied to all intermediate sizes.

Table 2 gives the results of recent tests on three samples each of six different gauges of wire (not specially manufactured), and shows how these compare with Pyc's proposed maximum values.

Test (4) is almost wholly covered by Test (2) and probably could be displaced by it, but the British Post Office and other users specify the following ductility test for wires which range in diameter from 0.0791 to 0.2237 in.

"The wire shall be capable of being wrapped in six turns round wire of its own diameter, unwrapped, and again wrapped in six turns round wire of its own diameter in the same direction as the first wrapping, without breaking; and shall be capable of bearing the number of twists set down in the table without breaking. The twist test will be made as follows:—

"The wire will be gripped by two vices, one of which will be made to revolve at a speed not exceeding one revolution per second. The twists thus given to the wire will be reckoned by means of an ink mark which forms a spiral on the wire during torsion, the full number of twists to be visible between the vices."

To show how this works in practice three standard 600 lb. wires were taken at random and the following results were obtained:—

G.P.O. Specification	Breaking Load (500 lb.)	Twists in 6 in. 2-Min. min.	Wraps per Foot min.	Ohms per Mile 1.4945
Sample I ...	1,895 lb.	28	66663	1.4590
" II ...	1,880 "	30	66662	1.4540
" III ...	1,900 "	28	66664	1.4591

The General Post Office tests for brittleness give a rough measure of the quality of the wires, and their value lies in the ease with which they can be applied, but it should be noted that the Department does not specify any extension test. It may be stated, however, with considerable confidence that wire which complies with Mr. Pyc's specification will also automatically comply with the Post Office specification. Apart from this, it does not seem clear why a wire which is to be erected and subjected mainly to longitudinal stress only should be tested by wrapping and twisting; the extension test would seem to be a more scientific way of determining the toughness of the metal. This opinion is confirmed by the action of the Wire Committee of the American Society for Testing Materials in offering explanations of their omission of these

TABLE 3.

Weight per Statute Mile			Approximate Equivalent Diameter			Minimum Breaking Load	Minimum No. of Twists	Maximum Resistance per Mile at 60°F. when reduced to Standard Diameter	Weight of Each Piece or Coil	
Required Standard	Minimum	Maximum	Required Standard	Minimum	Maximum				Minimum	Maximum
Lb.	Lb.	Lb.	In.	In.	In.	Lb.		Standard Ohms	Lb.	Lb.
800	784	816	0.2237	0.2215	0.2250	2,400	115	1,0084		
600	588	612	0.1937	0.1918	0.1956	1,800	20	1,4645		
400	392	408	0.1582	0.1560	0.1598	1,250	25	2,1608	100	140
300	294	306	0.1370	0.1350	0.1384	950	30	2,9291		
200	196	204	0.1119	0.1108	0.1130	650	20	4,3036		
150	147	153	0.0969	0.0959	0.0979	490	25	5,8582		
100	98	102	0.0791	0.0783	0.0799	330	30	8,7873	75	120

wrap and twist tests from their specification for hard-drawn copper wire.

#### ELASTICITY.

In view of the extensive and increasing use of copper conductors on overhead lines, railways, and tramways, and the great importance of the elastic properties of the wire in relieving strains, it seems desirable that any definition of hard-drawn wires should also include a reference to its "limit of proportionality" (elastic limit), as it does in many foreign specifications, and also, at first sight, to its modulus of elasticity. There are, however, practical difficulties in making these delicate measurements in works routine, and further reference will be made to these points.

The limit of proportionality varies from about 50 per cent for wires of 0.08 in. diameter to about 70 per cent for wires of 0.5 in. diameter when measured on 10 in. samples. The Engineering Standards Committee might stipulate for a minimum limit of proportionality for each standard size of hard-drawn wire, and might state the conditions under which the test should be carried out.

These should include:—

- (1) A statement as to the temperature (preferably 20° C.), although the percentage extension does not appear to be affected by variations within the atmospheric limits in the United Kingdom.
- (2) The type of apparatus and the conditions under which it should be used.
- (3) A statement of the length of the test piece.

An excellent basis for the above is to be found in the Engineering Standards Committee's Report No. 55, which contains the results of an investigation carried out by the National Physical Laboratory on some of the standard sizes of wires used by the British Post Office.

I would suggest that the Institution (through the Research Committee) would confer a great boon on the electrical industry if it would carry through an investigation on similar lines for all standard circular wires from No. 5 S.W.G. (0.212 in. diameter) to 7/0 S.W.G. (0.5000 in. diameter). The values could then be interpolated for all other sizes of wire by using a large-scale curve which embodied the results of the two investigations.

I would also suggest that the investigation should include work on stranded conductors. From the small amount of work which I have done on this point, there seems reason to believe that the limit of proportionality is higher for a given section of stranded conductor than it is for the corresponding section of solid conductor.

On all strands containing more than three wires, a considerable number of tests show that the effective strength should be taken as 10 per cent below that of the same number of straight wires. This appears to be due to the difficulty of getting the strain evenly distributed among the wires of a strand by any form of grip, and to the fact that the layers of wires are of unequal length, especially in the case of a large strand.

The subject of the elasticity of hard-drawn conductors has not attracted much general attention in this country, but important references to it have been made, notably by Mr. W. B. Woodhouse and by Mr. G. Carr.\*

\* *Journal I.E.E.*, vol. 44, p. 802, 1906.  
 † Professional Paper No. 26 ("Aerial Wire Construction") of February 1909, before the Institution of Post Office Electrical Engineers.

and in the Engineering Standards Committee's Report No. 55, already referred to. Mr. Carr entered a plea that 200 lb. wires should be made the minimum allowable on main telegraph lines because "the limit of elasticity is seldom reached," and it is noteworthy that the Board of Trade's electrical adviser has since debarred the use of any smaller conductor than this on an overhead high-pressure line.

In the United Kingdom the regulations of the Board of Trade provide that a conductor shall be erected with such a minimum sag that at 22° F. and with a wind pressure of 25 lb. per square foot of effective area the stress in it (excluding its elasticity) shall not be more than one-fifth of the breaking load, and that an accumulation of snow may be ignored. The rule has the virtue of being simple and on the safe side for English conditions, but it results in abnormal dips on small wires, of which No. 11½ S.W.G. is the smallest allowed.

It may be suggested for consideration that the proper procedure would be to decide what would be the worst conditions under which a conductor will have to work, and then to erect it so that under those conditions it will not be stressed beyond its limit of proportionality. For instance, the engineers of some of the most important Canadian power-transmission lines have decided, after long experience, that for the ordinary sizes of conductors used, the worst conditions may be taken as  $\frac{3}{8}$  in. thickness of sleet collected on the wire at 32° F. and a wind pressure of 11 lb. per square foot of effective area, and that under these conditions a factor of safety of 2 is required, which is within the limit of proportionality.

Whether the sag under the worst conditions is, however, calculated one way or another, the elasticity of the wire ought to be taken into consideration in arriving at the correct sag to be given when the wire is erected, so that under the worst conditions the sag will not be greater than that calculated. The wire cannot possibly be erected under the assumed worst conditions, and it has to be sagged on comparatively still days at a temperature of, say, 50° F. to 70° F.

Suppose a wire has been erected with the requisite sag under the worst conditions; then, when the wind drops, the wire is relieved of a certain amount of stress and it contracts by an amount depending upon the stress it has been relieved of and upon the modulus of elasticity. In the very act of contracting, however, it diminishes the sag, and this again puts a greater stress on the wire and tends to stretch it back to its original position; consequently, the actual sag taken up by the wire is a matter of somewhat intricate calculation.

Again, suppose a wire is hanging with a certain sag at a certain temperature and the temperature rises, say, 20° F., the length of wire in the span will increase by an amount depending on the coefficient of expansion of the metal. This lengthening would increase the sag, but increasing the sag reduces the tension in the wire; and again the wire by reason of its elasticity will contract by a certain amount depending on the stress it has been relieved of by the lengthening of the wire and the modulus of elasticity.

It is rather tedious to calculate from the worst sag under windage and low temperature what the erecting sag will be at, say, 60° F. with no wind blowing, but the following formulæ (the form of which is due to Professor A. Still)

will be found both useful and accurate and they afford a ready means of obtaining the result. The most convenient way to use the second formula is by assuming values of  $d_s$  and plotting a curve from the values of  $t_s$  so obtained, from which curve the sag at any required temperature can be read.

$d$  = sag in feet under the worst conditions, as calculated from the usual formula  $d = l_s W / (8 s)$ .

where  $l$  = length of span in feet ;

$W$  = resultant of weight and wind pressure in lb. (per foot) ;

$s$  = tension in conductor in lb. ;

$d_s$  = corresponding sag at the same temperature when wind and ice are removed ;

$W_1$  = weight per foot of wire only ;

$M$  = modulus of elasticity (say 18,000,000) ;

$A$  = cross-section of wire in sq. in.

Then to find  $d_s$  use the formula

$$\frac{W_1}{d_s} - \frac{W}{d} = \frac{64 (d_s^2 - d^2) M A}{3 l^3}$$

From  $d_s$  it is possible to find the sag  $d_s$  at any other temperature, from the formula

$$l_s - l_t = \frac{8 (d_s^2 - d_t^2)}{(3 l^3 + 8 d_s^2) C} + \frac{s}{M A C} (1 - d_s)$$

where  $l_t$  = temperature in degrees F. with sag  $d_s$  ;

$l_s$  = any other temperature in degrees F. ;

$d_s$  = sag at temperature  $l_s$  ;

$C$  = coefficient of expansion per degree F.

These formulae can also be used for calculations on loaded and unloaded copper catenary systems.

#### MODULUS OF ELASTICITY.

An examination of the load-extension curve of any hard-drawn copper wire will show that the modulus must be constant for the particular size, since the curve is a straight line up to the limit of proportionality, but the modulus is not necessarily the same for different sizes of wire.

In making measurements for true modulus values it is, in my opinion, necessary to work on long lengths of wire which approximate to the span length employed on a tramway or other overhead line. I have been led to this conclusion by a study of the results recorded by the National Physical Laboratory in the Engineering Standards Committee's Report No. 55 on lengths of wire up to 50 feet, and also of the method described by Mr. W. B. Woodhouse before the Institution in the paper already referred to. His tests were made with No. 6 S.W.G. wire on a span of 110 feet, and, assuming the correctness of his measure-

ments, it may be deduced from them that the modulus varied from 18,700,000 to 20,700,000 and gave an average value of 20,000,000. The method and the long length of the test-piece would tend to eliminate sources of error.

The moduli given in the Engineering Standards Committee's Report No. 55 vary between 17,200,000 and 18,200,000 on the second and third applications of the load, and particular attention is drawn to the different values of the readings on the first and subsequent applications of the test load. On the first application of the load the kinks in a coil of wire were pulled straight and the "apparent moduli" varied from 12,300,000 to 15,300,000, while on the subsequent loadings the values were as stated, viz. 17,200,000 to 18,200,000.

In the Report referred to, the following statement is made :—

"It is thought, however, that the values of the "apparent" moduli will be of interest and use, since it is these which must be taken into account in the erection of long lengths of wire."

I venture, with all respect, to express disagreement with this statement, because on all well-constructed overhead lines the wires should first be strained to a tension higher than that at which they will be permanently bound in. The object of this is to get rid of the kinks referred to in the Report and to allow the wires, especially stranded conductors, to "settle down." This procedure makes it permissible to take advantage of the real modulus value.

In view of the figures and considerations quoted, I consider that it is permissible to adopt an all-round value of 18,000,000 in future instead of the usual text-book figure of 16,000,000. I am afraid, however, that it will not be practicable to embody a minimum modulus value in ordinary specifications of hard-drawn copper, in view of the difficulties and delays which would occur in most works in carrying out the sensitive tests required. In special cases, however, it might be advisable to specify a minimum value and to make arrangements with the National Physical Laboratory or other testing institution to provide the necessary apparatus and carry out the tests on specimens provided for the purpose.

#### TENSILE STRENGTH.

An interesting point arises out of the widely-held belief that the strength of hard-drawn wire lies in its skin being hardened during the drawing process. An examination of the matter does not disclose any conclusive evidence in support of this theory.

I have investigated it and have obtained the following results (Table 4), starting with a length of 0.400 in.

TABLE 4.

Test		Diam.	Area	Breaking Load	Breaking Stress	Percentage Elongation on 10 in.
No.		In.	Sq. in.	Lb.	Tons per sq. in.	Per cent
1	Original wire	0.400	0.1257	6,950	24.70	2.50
2	Turned down	0.376	0.1110	6,160	24.85	—
3	"	0.351	0.0907	5,520	25.42	—
4	"	0.326	0.0834	4,745	25.49	—
5	"	0.301	0.0711	4,160	25.70	—
6	"	0.276	0.0598	3,425	25.60	1.66
7	"	0.250	0.0491	2,840	25.80	—

diameter hard-drawn circular trolley wire. Six pieces were turned down to different diameters with great care in order to avoid undue heating of the specimens.

This result is not, of course, absolutely conclusive, because the work done on the wire in the lathe will have some effect in hardening the skin at each stage.

A series of micro-photographs of a transverse section of trolley wire (magnified 100 times) have also been taken, and from them it appears that the copper is of equal density throughout.

The question of whether the strength of copper wire is uniform throughout its cross-section is of great importance in connection with contact wires on railways and trolley wires on tramways, because they are subject to wear from pantographs, slider bars, and trolley wheels. An investigation was made on this point recently on a 0.25 sq. in. grooved contact-wire in connection with a railway-electrification scheme which is now under construction.

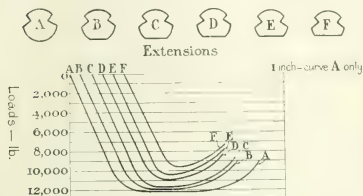


FIG. 5.—Autographic Record of Tensile Tests on Hard-drawn Copper Trolley Wire, Grooved Section.

The wear on the wire was reproduced by gently filing away the face, and the cross-sectional area was accurately determined by weighing the specimens. The results are shown in Fig. 5. The tensile strength of the original section of this wire was 21.8 tons per square inch and the extension was 6 per cent on a 10 in. piece. It also withstood the following severe torsion tests without showing any signs of fracture: The wire was given  $3\frac{1}{2}$  complete twists in a length of 8 inches.

#### EFFECT OF TEMPERATURE ON THE STRENGTH OF HARD DRAWN COPPER.

The current which any bare overhead conductor will carry for a specified temperature-rise under still-air con-

ditions can be predetermined by the use of Professor George Forbes' formula,

$$I = D^2 \left( \frac{t \pi H}{4 R \times 0.24} \right)$$

where I = current in amperes;

D = diameter of solid wire in cm.;

t = temperature-rise in degrees C.;

H = coefficient of radiation (0.0003 for solid wire or 0.00344 for stranded conductors);

R = specific resistance of copper per centimetre cube at limiting temperature;

0.24 = calories in a joule.

$$\left( \frac{t \pi H}{4 R \times 0.24} \right) = 44,250 \text{ for a limiting temp. of } 125^\circ \text{ F. (for solid wire),}$$

$$= 50,750 \text{ for a limiting temp. of } 125^\circ \text{ F. (for stranded wire),}$$

$$= 80,840 \text{ for a limiting temp. of } 175^\circ \text{ F. (for solid wire),}$$

$$= 92,300 \text{ for a limiting temp. of } 175^\circ \text{ F. (for stranded wire).}$$

The question of the maximum permissible temperature of hard-drawn copper is of importance on overhead power and trolley wires because of the effect of heat in reducing their tensile strength, especially when under tension.

The National Physical Laboratory found that on wires up to 0.194 in. diameter "the reduction in breaking load due to temperature appears to be approximately one-tenth of 1 per cent of the breaking load at normal temperature per degree Centigrade rise of temperature."

Test	Amount Filed on Working Face	Cross-sectional Area	Maximum Load	Maximum Stress	Yield Load	Yield Stress	Limit of Proportionality
A	Original wire	Sq. in. 0.249	Lb. 12,150	Tons per sq. in. 22.0	9,500	Tons per sq. in. 17.2	Per cent 78
B	0.030	0.234	11,900	22.6	9,500	18.1	79
C	0.060	0.226	11,650	23.0	9,500	18.7	81
D	0.090	0.221	10,900	22.0	9,500	19.2	87
E	0.120	0.207	10,300	22.2	9,000	19.4	87
F	0.150	0.195	9,600	22.0	8,500	19.5	88

I have carried out a series of tests on specimens of 4/0 S.W.G. copper trolley wire, diameter 0.400 in., using apparatus which did not admit of any such refinements as those at the disposal of the National Physical Laboratory, and I have obtained the results stated in Table 5.

I regard the results on Samples 13 to 18 inclusive as being more reliable than those on 4 to 9 inclusive, and they seem to confirm that the National Physical Laboratory's determination, quoted above, will hold good for all sizes of circular copper wire.

A number of experiments have been carried out by Dr. F. J. Brice to determine the permanent effect of prolonged heating on the strength of wire, and he has very kindly given me the (see Table 6) unpublished results of

experiments on trolley wires. All the figures given are the mean of three determinations, and the test after heating was made when the copper had cooled to atmospheric temperature.

From these results it will be seen that with 1/0 S.W.G. trolley wire the permanent decrease in strength after

TABLE 5.

Samples	Temperature ° C.	Breaking Load in lb.	Average. Lb.	Percentage Drop in Breaking Load per ° C.		
1	15.5	6,937	7,043	0.0821		
2	"	7,080				
3	"	7,112				
4	63.0	6,800	6,770		0.0730	
5	"	6,700				
6	"	6,810				
7	82.0	6,700	6,700		0.0702	
8	88.0	6,640	6,640			
9	"	6,640	7,000		0.0933	
10	15.5	6,900				
11	"	7,000				
12	"	7,100	6,383			0.1045
13	110.0	6,350				
14	"	6,400				
15	"	6,400	6,148			0.1045
16	132.0	6,160				
17	"	6,135				
18	"	6,150				

(Samples 1 to 9 were from a batch of copper different from Samples 10 to 18.)

2 hours' heating at 150° C. (302° F.) is only 0.5 per cent and is negligible, while a 4/0 S.W.G. wire was not affected after 4 hours.

Among tramway engineers it is generally understood that the temperature of trolley wires never exceeds 220° F. (say 105° C.), and it is a fair deduction from the above tests that the limiting temperature is not reached. In view, however, of the fact that the rise of temperature occurs on

wires while under strain, it would not appear to be advisable to exceed a temperature of 250° F. in practice. At this temperature the tensile strength of the wire would be about 10 per cent less than at normal temperature, but the tension would be relieved to some extent by the expansion due to heating.

TABLE 6.

Diam. of Wire.	Duration of Heating	Temperature	Breaking Load before Heating	Breaking Load after Heating and Cooling	Extension after Heating
In.	Hours	° C.	Lb.	Lb.	%
0.324	2	150 to 152	4,766	4,740	2.2
0.324	4	100 to 105	4,766	4,600	2.2
0.324	1	100 to 102	4,766	4,701	2.2
0.324	60	320	4,766	2,852	44.0
0.372	6	195	5,856	5,745	2.5
0.372	60	190	5,856	5,793	2.5
0.400	4	151	6,761	6,756	2.5
0.400	4	150	6,761	6,757	2.5
0.400	2	200	6,754	6,684	2.5
0.400	6	200	6,754	6,691	2.5

In this connection it may be noted that the Engineering Standards Committee's Report No. 55 gives the coefficient of expansion of copper per degree C. as varying between 0.0000163 and 0.0000167. The average of these is equal to 0.0000093 per degree F. The voltage-drop due to resistance would appear to be the limiting feature in overhead wires rather than the question of temperature. In case it should be necessary to know the resistance of copper resulting from change of temperature, this formula may be used:—

$$R_t = R_0 (1 + 0.0042 t),$$

where  $R_0$  = the resistance at 0° C.,

$$R_t = \quad \quad \quad t^{\circ} \text{C.}$$

## INSTITUTION NOTES.

## PERIODS FOR REPAYMENT OF MUNICIPAL LOANS.

The following correspondence has passed between the Institution and the Local Government Board:—

## THE INSTITUTION OF ELECTRICAL ENGINEERS.

20 May, 1915.

The Rt. Hon. WALTER H. LONG, M.P.,  
President of the Local Government Board.

Sir,

The Council of the Institution of Electrical Engineers having been approached last year by some of the leading members of the Institution, appointed a Committee to consider and report upon the periods sanctioned by the Local Government Board for the repayment of Municipal Loans, and I am desired to ask that you will be so good as to receive a deputation of the Council on the subject of an alteration in the periods at present allowed in regard to (a) cables, (b) conduits, (c) storage batteries, and (d) reinforced concrete, upon which I now have the honour to lay the Council's views before you.

*Cables.*

The above-mentioned Committee placed itself in communication with some 40 members of the Institution in charge of electrical undertakings of Local Authorities in the United Kingdom, and from the information received it appears that the consensus of opinion of these members is that Underground Electric Cables have much longer lives than the periods at present allowed, namely:—

<i>Cables.</i>	Periods at present allowed	
	Years	
Laid in ducts on solid system ...	25	
Armoured laid direct in the ground ...	15	
ditto, but specially coated with jute and bitumen and covered with bricks ...	20	

From the data collected by the Committee, the Council feel no hesitation in asking the Board to allow in future a period of 30 years for all classes of Underground Cables, provided that they are substantially constructed and laid with due regard to the nature of the soil.

In this connection the Council point out that the transmission and distribution of electrical energy at a standard voltage continuously throughout the year and from year to year can only be maintained by frequent testing and efficient upkeep of the cables, which are thereby compulsorily kept in a high state of efficiency out of Revenue.

The Council also point out that, whatever the system of laying, the residual value is an important item.

*Conduits.*

The Council recommend that in the case of Cables drawn into substantially constructed conduits, the cost of the conduits and that of laying them should be treated apart from that of the cables and that the expenditure thereon be allowed a period of 60 years, which period is suggested for the purpose of accommodating two installations of cables each having a life of 30 years.

*Storage Batteries.*

The Council point out that since the loan periods were first settled, great improvements have been made in Storage Batteries, and also that in order to obtain useful work from them, batteries must be maintained from year to year in good working condition.

The Council therefore recommend that 15 years should be fixed as the loan period for Batteries in cases where the Board is satisfied that adequate provision has been made for the proper maintenance of the Batteries.

*Reinforced Concrete.*

In view of the evidence now available as to the life of reinforced concrete, the Council are of opinion that the loan period for Reinforced Concrete should be extended from 15 to 30 years, which is the period allowed by the London County Council.

I am, etc.,

(Signed) JOHN SNELL,  
President.

LOCAL GOVERNMENT BOARD.

10 August, 1915.

Sir,

I am directed by the Local Government Board to advert to your letter of the 29th of May last, asking them to receive a deputation of the Council of the Institution of Electrical Engineers on the subject of an alteration in the periods allowed for the repayment of loans sanctioned by them for (a) cables, (b) conduits, (c) storage batteries, and (d) reinforced concrete, in connection with electricity undertakings.

The Board do not think that there would be any advantage in the attendance of a deputation. They have given careful consideration to the representations in your letter, and they direct me to make the following observations:—

*(a) Cables.*

The period for underground cables has recently been altered to 25 years for all types. The Board do not consider that any longer period can properly be allowed.

*(b) Conduits.*

The Board could not agree to the proposal that 60 years should be allowed for conduits. At present the period allowed is the same as for cables, but the Board would be prepared to grant 30 years in suitable cases when that period is asked for.

*(c) Storage Batteries.*

The Board have decided to allow a uniform period of 7 years in future for storage batteries instead of the 5 years hitherto usually fixed. They cannot assent to any further extension.

*(d) Reinforced Concrete.*

The period for reinforced concrete varies with the character of the work, and the Board do not at present see any reason to alter their practice.

I am, etc.,

(Signed) A. J. A. BALL,  
Assistant Secretary.

Sir JOHN SNELL,  
President of the Institution  
of Electrical Engineers.

## PRESENTATION BY H.M. QUEEN ALEXANDRA.

Her Majesty Queen Alexandra has presented to the Institution an early telephone set made on board H.M.S. *Thunderer*, which was installed at Marlborough House in 1878 and was for many years in use between Her Majesty's room and the schoolroom of the Royal Children.

## ELECTION OF HONORARY TREASURER.

The Council have elected Mr. J. E. Kingsbury to be Honorary Treasurer of the Institution in place of the late Mr. Robert Hammond.

## ELECTION OF AN HONORARY MEMBER.

The Council have elected Monsieur Maurice Leblanc to be an Honorary Member of the Institution.

## RESEARCH.

The Council have made application in the name of the Institution for a grant under the Government scheme for the organization and development of industrial research.

On the 7th September last, Sir John Snell and Dr. S. P. Thompson, F.R.S., on behalf of the Research Committee, had an interview with Sir William McCormick, Chairman of the Research Advisory Council which has been appointed by the Board of Education to deal with this matter. The views of the Research Committee were given at the interview, together with a statement of the researches in hand or decided upon; and a summary of the points discussed was afterwards sent to Sir William McCormick.

A letter has since been received from the Research Advisory Council asking the Research Committee to submit schedules of particulars of the above-mentioned researches, with notes of the grants desired for each by the Institution, and various other details, and a reply containing the desired information has been sent to the Advisory Council.

## RUBBER RESEARCH.

The Council have approved a report of the Research and Wiring Rules Committees urging the desirability of carrying out an investigation into the mechanical and physical properties of rubber considered as an insulating material, and they have included it in the list of researches for which a grant is being sought from the Research Advisory Council of the Board of Education.

## ROLL OF HONOUR.

Up to the 20th November, 1915, the following members were reported to have lost their lives in the service of their country :—

<i>Name.</i>	<i>Corps, etc.</i>	<i>Rank.</i>
<i>Killed in Action.</i>		
Casson, W.	7th London Regt.	Captain
Tidd, E. G.	6th Highland Light Infantry	Captain
<i>Killed.</i>		
Slater, G. L.	H.M.S. <i>Butwick</i>	Captain R.N.

## ASSOCIATE MEMBERS.

<i>Killed in Action.</i>		
Brydon, A. W.	2/4th Queen's Royal West Surrey Regt.	Lieutenant
Henry, W. J.	Anson Batt., R.N.D.	Sub-Lieut.
Labour, H.	French Army	
Lloyd, N. V.	6th Manchester Regt.	Private
Marsh, H. H. S.	2nd London Divisional R.E.	Major
Moffet, J. L.	3rd Royal Scots Fusiliers	2nd Lieut.
Newman, V. W.	Loyal North Lancs Regt.	Captain

*Died of Wounds.*

Doig, A. M.	6th Manchester Regt.	Private
Gilbert, J.	6th Manchester Regt.	Private
Hulton, R. P.	Divisional Engineers, R.N.D.	Corporal.
Read, A. H.	Divisional Engineers, R.N.D.	Lance-Corpl.
Tilley, F. E.	Divisional Engineers, R.N.D.	Sapper
Winkworth, W.	5th Northumberland Fusiliers	2nd Lieut.

## ASSOCIATE.

<i>Killed in Action.</i>		
Gardiner, A.	Royal Engineers	Major

## GRADUATE.

<i>Died of Wounds.</i>		
Warburton, P. A. E.	New Zealand Engineers	Sapper

## STUDENTS.

<i>Killed in Action.</i>		
Byng, H. G.	2nd Border Regt.	2nd Lieut.
Gudgeon, S.	3rd Manchester Regt.	2nd Lieut.
Miller, C. W.	6th Manchester Regt.	Lance-Corpl.
Slater, E. C. H.	6th Manchester Regt.	Private
Wilson, E. W.	West Yorkshire Regt.	2nd Lieut.
Young, A. Y.	2nd Royal Scots Fusiliers	2nd Lieut.

*Died of Wounds.*

Ogden, A. H.	Divisional Engineers, R.N.D.	Sapper
Swinton, E.	Royal Field Artillery	2nd Lieut.

*Died.*

Donald, J. A.	Divisional Engineers, R.N.D.	Sapper
Foote, N. V.	2nd Australian Light Horse	Trumpeter
Pullen, W. W.	Divisional Engineers, R.N.D.	Sapper
Woodside, H.	Divisional Engineers, R.N.D.	Sapper

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### SOME DIFFICULTIES OF DESIGN OF HIGH-SPEED GENERATORS.

By Professor A. B. FIELD, Member.

*(Paper first received 10 December, 1914, and in final form 25 January, 1915; read before THE INSTITUTION 25 November, before the BIRMINGHAM LOCAL SECTION 24 November, before the MANCHESTER LOCAL SECTION 30 November, and before the YORKSHIRE LOCAL SECTION 8 December, 1915.)*

Progress in the design and manufacture of electrical generating machinery has been recorded, year by year, by the many differing features which have characterized the output of our manufacturing establishments.

New types of machinery have made their appearance; new materials, and new applications of existing materials, have been developed; a reduction of weight and size for a given output, and a reduction of manufacturing costs have been effected; ratings have been standardized, and so on. In fact, with all due deference to the occasional cynical buyer, who sometimes looks askance at the innovations, and sometimes even questions their progressive tendency, we certainly have to record from time to time increased effectiveness for a given cost of production, and extended fields of application of existing types.

An illustration of this process of evolution may be found in the development of steam turbo-generators. In early days the limitations of speed imposed by the generator design acted somewhat as a handicap in the rapid development of the turbine, but recent years have witnessed a concurrent development of both turbine and generator, with the raising of the speeds of the combined sets to the limits corresponding to 2-pole and 4-pole designs. Simultaneously, the output per machine has been greatly raised, until many sets are now running capable of giving continuously up to 6,250 k.v.a. at 3,600 r.p.m., 20,000 k.v.a. at 1,800 r.p.m., and higher ratings at 1,500 r.p.m. (60, 50, and 25 periods).

In attaining these results many difficulties have been overcome in as many different ways, and it has been thought that a general discussion of a few of them would be of great interest. By way of introduction, the author feels that he can do no better than to describe some of the difficulties encountered, and the means of overcoming them adopted by one large manufacturing concern in the United States with which he was connected for a few

years and whose engineering directors have been broad-minded enough to encourage such a discussion here.

In order to put the matter upon a practical basis, it may be best to take a specific example; and reference will chiefly be made to a 20,000-kw. 3-phase machine having the following characteristics:—

Speed ... ..	1,800 r.p.m.
Poles ... ..	4
Cycles ... ..	60
Kilovolt-amperes ... ..	20,000 at power factors from 1.0 to 0.8
Voltage ... ..	13,200
Rotor dimensions ... ..	51 inches x 75 inches

About a couple of years ago some half-dozen of these machines of almost the same design except as to voltage were put in hand in the shop simultaneously, in addition to a number of other 2-pole and 4-pole machines of unusual sizes and proportions. Some of the latter will be referred to in illustration of special features.

The design of such a machine represents to a greater degree than is usually the case a compromise between many conflicting mechanical and electrical requirements. Viewed in a general way, there is first the problem of constructing a rotor which must necessarily weigh something of the order of 60,000 lb., and which will be running with a peripheral speed in the neighbourhood of 24,000 feet per minute. Such a rotor, unfortunately, must be of the nature of a cage, being irregularly cut into from the periphery and carrying much metal which is not self-supporting. The centrifugal force acting upon a 1-lb. mass at the periphery will be about 1 ton.

To fix our ideas, let us glance at Fig. 1, representing a cross-section of the steel of such a rotor when constructed from the point of view of mechanical stresses upon one of

the simplest and most symmetrical plans. It will not be necessary to labour this description before an engineering gathering; it is sufficient to say that the form and kind of material entering into the construction of the rotor demand



FIG. 1.

the most careful consideration, and that certain features assume importance which could be largely ignored if the working speed were reduced by, let us say, only 20 per cent.

#### ROTOR MATERIAL.

In the first place, it is impracticable to use a through shaft with a hollow body or with discs threaded upon it—a construction which, however, is permissible and satisfactory in some smaller examples of this class of work. The rotor body could be made as a solid steel casting or forging in one piece with the shaft ends, and it would be quite possible to obtain such a piece with a fair amount of forging work done upon it; for example, an ingot diameter of about  $6\frac{1}{2}$  feet would allow of a 2:1 reduction of area on the main section.

For lower speeds or smaller diameters such a construction is very often advantageously used, as is illustrated in Fig. 11. Such properties of the material as are desirable in the case of the larger machine in question are, however, difficult to obtain commercially. It must be remembered that in many of the more general engineering applications of forgings of the form in question (other than high-speed generators), bending and twisting effects have chiefly to be provided against. These involve longitudinal tensile stresses and shearing stresses, which reach their maxima at the periphery; ductility is chiefly of importance near the surface and in the directions indicated. Material near the centre is of no value, and in fact is frequently removed by boring, so as to allow of better annealing conditions, and for other reasons. In our case, on the contrary, consider-

able radial tensile stresses are encountered, and the ductility in this direction is chiefly required far below the surface. Again, the radial tensile stress right into the centre is not inconsiderable, and were the central material removed by boring, the tangential tensile stresses, at normal speed, of the material near the bore would be in the neighbourhood of 20,000 lb. per square inch. To this must be added the local excesses due to such lack of symmetry as occurs.

Several large rotors, weighing up to some 45,000 lb., had been constructed successfully by the Westinghouse Company of America, using two steel castings united on the rotor centre-line. Many experiments were needed before such castings could be produced with even moderately satisfactory qualities, and then only at considerable cost in discarded material and not infrequently in rejected castings. Ordinary carbon steel, and also low-percentage nickel steel had been used for these. At an early date in the use of these castings, the Company had made elaborate tests by taking out several test-bars in different directions and at different radial depths in each of many sections, progressing from the top end to the bottom end of the mass as cast. Chemical analyses were made at corresponding points to trace the segregation occurring. In one such series of tests, over 100 test-bars were taken out of the casting, with a corresponding number of analyses. At a later date, tests were similarly made on a large forging, particularly to determine the properties in a radial direction and at different positions in the forging.

The construction initiated by the Westinghouse Company for the large rotors under consideration was adopted after such investigations upon the regular market productions obtainable in the United States, and in consequence of realizing that one must be prepared to build turbo-generators at all times, irrespective of market conditions (*i.e.* when the steel mills are busy and therefore not anxious to devote extra and special care to the production of material of unusual properties to satisfy the requirements of critical inspectors), and that it is of great manufacturing importance to have designs such that the material may, as far as possible, be obtained from any one of many sources in the country. These are some of the more important reasons which influenced a decision in favour of the material and construction described below. It will surely be unnecessary for the author to disavow any intentions of maintaining that such is the only safe or sound engineering procedure.

Now a difficulty, in some respects similar to that indicated above, had previously arisen in connection with large forgings for high-speed water-wheel-driven generators, and it had been overcome by the use of open-hearth rolled plates consolidated and mounted on a shaft. Compared with rolled plates there is probably no other form in which such large masses of steel can be produced at a low cost having such good physical properties in directions of two dimensions. This is partly due to the great demand for such plates for a large variety of engineering purposes, which has resulted in much equipment being put down for their production and treatment. It remained open, in the case of the water-wheel-driven rotors, to use either comparatively thin boiler plate such that the surface need not be machined and the buckling of the plates could be taken care of sufficiently by an ample section of bolts or rivets, or to use thicker plates machined on both sides.

In the case of a number of important machines the latter alternative had been used by Behrend, who for evident reasons used the thickest rolled plate that was commercially available. By "commercially available" is meant plate that is readily obtainable at a number of mills and is similar to that in regular demand for other purposes. This would limit us generally to plate about  $2\frac{1}{2}$  inches thick in the rough. One batch of about 100 tons of such steel, about  $2\frac{1}{2}$  inches thick, produced under unusually favourable conditions and containing a small percentage of nickel, gave tests averaging approximately as follows:—

Ultimate tensile strength ...	80,000 lb. per sq. in.
Yield point ... ..	53,000 lb. per sq. in.
Elongation ... ..	26 % in 2 inches
Reduction of area ... ..	60 %
Bending test ... ..	Strips the full thickness of the plate bent through 180° and closed down without fracture

The results that can be expected generally on commercial material will be given later.

#### PLATE-BUILT ROTORS.

In the case of the steam-driven turbo-generators under consideration, this plate material appeared very attractive, combining, as it did, a very low cost per pound with entirely reliable properties from the periphery to the centre and

plates slightly rabbeted into one another, and into a flanged shaft at each end. A rabbet about  $\frac{1}{4}$  inch deep is ample; and by means of a group of four or six chrome-nickel steel bolts, each about 4 inches in diameter, a 50- to 56-in. diameter rotor can be constructed with practically the solidity of a single piece. These bolts can be tightened up until they have a stress of about 40,000 lb. per square inch, and in the actual construction of the rotors special means are adopted to ensure obtaining a tension in the bolts roughly corresponding to the desired amount. This has been done by tightening the nuts until a specified elastic elongation of the bolts has been attained, this elongation being a distinctly measurable amount, approximately 1 to 10 inch in many cases.

Another method that had been in use for some time in similar operations consists in applying the required force to a 5-ft. or 10-ft. spanner by means of the shop crane. Using a regular suspension weighing machine on the crane hook, this force can be measured, and hence the final tension in the bolt determined, provided it is known what coefficient of friction should be allowed with respect to the rotation of the nut. Comparing the two methods, and from other direct means of check, it was found that a coefficient of friction of about 0.16 suited the conditions of lubrication. The crane-and-weighing-machine method has some advantages in practical operation over the extension method, and has been generally used.

It may be contended that the plate construction here described only partially overcomes the difficulties indi-

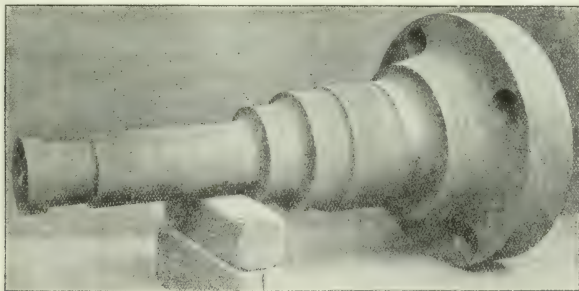


FIG. 2.

from end to end of the rotor. Its use would result in the production of a rotor in which practically the only internal stresses were intentional ones; there would be nothing corresponding to the huge initial stresses to which solid forgings and castings are liable. With the plate construction every cubic inch of material would be within an inch or two of a forged surface (or the equivalent). The impossibility of using a central shaft, however, at first discouraged the idea of a built-up plate rotor. It was due to the suggestion of Behrend, again, that the feasibility was demonstrated of constructing such a rotor with the

cated above, inasmuch as it is still necessary to have heavy forged shafts with large flanges forged on them of the full diameter of the rotor. However, the difficulty of securing a satisfactory forging has not only been reduced as the consequence of the much smaller weight of each single-piece forging, but the axial length of the large-diameter part can be kept down to such dimensions that in addition to the usual radially-directed forging process, the material can be worked in an end-wise, *i.e.* axial, direction. While this method of working the material increases the cost of the forging, it ensures good pro-

perties in a radial direction. In other words, to produce the flanged shafts for the severe cases under discussion, a large bloom is forged down to a diameter intermediate between that of the flange and that of the large end of the shaft, and stepped off; the forging is then placed with its axis vertical in a die under a forging press, and the increased flange diameter obtained by end-wise forging. Radial test-bars taken out of the flanges of such pieces, even at a depth of 8 or 9 inches from the surface, have shown excellent results; so that one can practically depend upon getting an elongation of over 20 per cent in 2 inches, with a reduction of area exceeding 35 per cent, in a standard  $\frac{1}{2}$ -in. test-bar from a carbon-steel forging, giving an ultimate tensile strength of 70,000 lb. per square inch and a yield point of 35,000 lb.

In Fig. 2 is shown a partially-machined shaft produced in the way described.

Returning to the matter of the plates, when these can be obtained locally it is frequently convenient to use ingots of such size that one disc is obtained out of each plate, so that the complete plate can be delivered to the factory, put upon a boring mill, and the required disc parted out of it, the scrap material being returned to the rolling mill. In this way, incidentally, we have an easy check upon the amount of discarded material from the top and bottom ends of the ingot; and we save the shearing labour, and also the machining of a considerable radial margin which must be left when the plates are rough-sheared to circular shape at the mills. However, if the material must be transported over any considerable distance, it is satisfactory to rough-shear the plates at the mill to an approximately circular shape; in which case, with the thickness of plate mentioned above, it is sufficient to specify a rough diameter of about 2 to 3 inches greater than the required finished diameter. With this margin the material injured by shearing will be removed.

As regards the thickness, the plate can easily be supplied flat enough for a  $\frac{1}{4}$ -in. allowance to be sufficient for machining both sides, especially as the diameter of the rabbet projection on one side of the plate is only about half that of the plate itself.

Whether the material is supplied sheared or in the rectangular plate, it is marked by the rolling mill to indicate the part corresponding to the top end of the ingot, and care is always taken to transfer this mark while machining, so that a corresponding indication appears on the finished plate. When drilling and assembling the plates, this marking enables us to rotate each plate, say, 60° with respect to the plate below it in a constant direction, so that in the complete rotor there is practically no remnant of the slightly different properties of the plate in directions along and across the direction of rolling.

The properties which can be expected from this material as an average are somewhat as follows:—

Ultimate strength ...	67,000 lb. per sq. in.
Yield point ...	34,000 lb. per sq. in.
Elongation ...	27 % in 2 inches
Reduction of area ...	43 %

For a cold bending test, a strip of the full thickness of the plate will generally bend through 180° round a 3-in.

diameter pin. For purchasing specification purposes, it is necessary to allow some margin on these figures, particularly in the matter of ductility. As regards the market price, this is in the neighbourhood of 0.8 to 1d. per lb. with ordinary conditions of the steel market.

It is hardly necessary to point out that this plate material has a clearly defined field of usefulness. While showing excellent results in an application suited to its peculiar properties, such, for example, as that described above, the material may fail completely if used in an unsuitable manner. For instance, in directions at right angles to its plane the plate necessarily has poor properties; there is liable to be some lamination, and remnants of piping are likely occasionally to appear. The plates, therefore, should not be used in a manner which will involve much tensile stress at right angles to their plane, or even considerable shearing stress in their plane.

#### CRITICAL SPEED.

The next question to arise is that of the critical speed. While many large rotors are running satisfactorily at operating speeds above their critical speeds, it is believed that there is a distinct advantage in keeping the critical speed above the running speed, when this is feasible. To mention one point: Experience has shown that in the case of some 4-pole machines of the former class, running perfectly under normal conditions, a short-circuit of even a few turns of rotor winding on one pole may result in serious vibration. On the other hand, one of the machines now under discussion and designed for a high critical speed was purposely run with two-thirds of the winding of one pole short-circuited, and no considerable difference in the running was noticeable.

If it is decided to run below the critical speed in the case of these large machines, concessions must be made in many features affecting the critical speed. The rotor body must be as short and light as possible, involving a high air-gap density and a severe working of the stator material in the neighbourhood of the air-gap. The shaft diameter must be kept large, and high peripheral speeds must be tolerated for journals and slip-rings. In the case of the present machines, the journal speed approaches 6,000 feet per minute; and for the slip-rings a speed of about 11,000 feet per minute becomes necessary, even after adopting special means to keep the slip-ring diameter as small as possible, short of using a hollow shaft and slip-rings outside the bearings. The span between the journal centres especially must be kept small, which imposes some limitations upon the design of the stator end-windings, and necessitates the omission of blowers from the rotor. The lengthening of the rotor span, entailed by the use of blowers on the rotor, is greater than corresponds to the axial length of the blower openings on account of the provision that has to be made in the end-bells, and the necessity of being able quite easily to dismantle the end-bell structures without disturbing other parts of the machine.

In this connection it is of some interest to notice that a rotor constructed along these lines really has no true critical speed. The critical speed of a rotor of given dimensions depends upon its stiffness; the inverse of the stiffness we may measure roughly by the deflection of the

stationary rotor supported on its journals, per unit load applied at its centre. Now the rotor body as constructed consists of, first, small cross-sections (bolts) under great tension, and, secondly, comparatively large cross-sections (the plate surface around the bolt-holes) under compression. As long as these conditions subsist, the stiffness is the same as that of a solid mass having no partition planes, and it is unaffected by the stress distribution. When, however, the deflection reaches an amount such that the compressive stress in the plate at one side of the rotor vanishes, the stiffness for further deflection is immediately reduced, the effective area of the metal on the tension side changing from that of the whole section to that of the bolts only, as far as concerns the ratio of the further incremental loads and strains. Hence, to take a numerical case, we might say that for vibrations of amplitude below a small determinate amount, say  $a$ , the critical speed would be perhaps 2,400 revs. per min., while for vibrations above  $a$  in amplitude the critical speed is only 1,500 r.p.m. When running, then, at 1,500 r.p.m. the second critical speed cannot show itself, because the vibration can only start at 2,400 r.p.m. Again, when running at 2,400 r.p.m., the first critical speed can only show itself to the extent of a limited vibration, beyond which the rotor would find itself running at the wrong speed to vibrate. This is mentioned as a matter of more theoretical interest than of great practical importance.

#### ROTOR VENTILATION.

A matter requiring early attention would be the question of rotor coils and ventilation. It is extraordinary how large a rotor loss can be dissipated merely from the drum surface with no ventilation, and it is commonplace knowledge how little good some fairly elaborate ventilation systems are found to do. Nevertheless, it is possible to obtain very efficient ventilation, and our object of obtain-

other features of the machine that we shall have to adopt, is one combining an axial passage underneath the winding slots with a radial discharge distributed over a fairly wide central portion of the rotor. The plate construction here

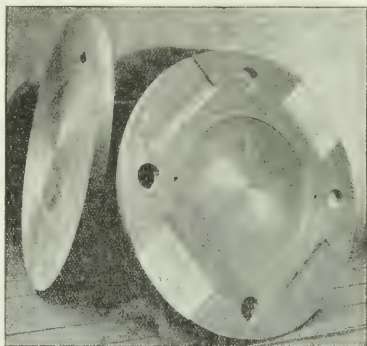


FIG. 3.

lends itself admirably to our requirements, inasmuch as we can readily obtain the radial ventilating spaces by means of a simple "slab-miller" operation upon the individual plates before assembly. This provides a vent  $\frac{3}{8}$  inch wide in the region of the slots and teeth, leaving the plate solid in the region of the pole. Were the rotor made of a single piece, the radial vent space could only

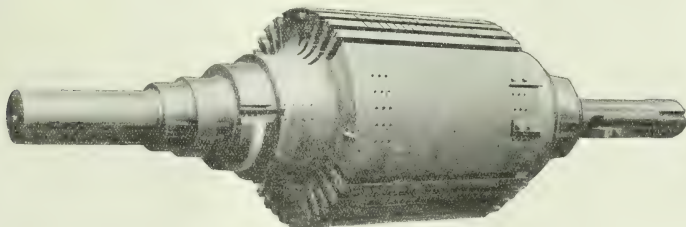


FIG. 4.

ing a small, short rotor can only be attained by taking advantage of every means to that end. It therefore becomes incumbent upon us to use a ventilated rotor, which necessitates cleansing the air supply before admission to the generator. In any case the objection which the purchaser sometimes raises to this air filtration should be discounted by reason of the great benefit which accrues to the stator from the absence of dirt.

The system of ventilation which lends itself best to the

be obtained reasonably by parting down grooves round the complete circle. The previous arrangement not only gives a very solid rotor by having the plates butt together up to their outside radius, but also the extra metal in the region of the poles is needed for magnetic reasons. The size of these rotors for their output is such that we begin to get some saturation in the poles, a condition rarely occurring in general in the case of 2- or 4-pole turbo-generators, except when artificially obtained.

Fig. 3 shows a pair of discs for a 4-pole rotor; in this particular case the discs have been parted out of the rectangular plates. The one disc is ready for assembly, having been milled on one side for the ventilation in the slot region, but the other disc has only been faced. After assembling the discs and shafts, the bolt-holes are to be reamed out, the bolts fitted, and the winding slots cut. The bolts are to be finally tightened after the slotting, and the heads of the nuts cut off. Fig. 4 gives a general idea of a 2-pole built-up rotor ready to receive its windings.

#### ROTOR WINDINGS.

As regards the winding, it may perhaps be said, without further discussing relative merits, that a separately-formed edge-wound coil, dropped turn by turn into the slots, is used, with solid mica insulation and a light steel cell to protect the insulation against the effect of the ventilating air. For several mechanical reasons, concessions are made in the electrical requirements of the winding, so that a comparatively wide strip (about  $1\frac{3}{4}$  inches) is used, with only three coils per pole, *i.e.* six slots per group, in the 4-pole rotor. The field windings, even when of this width, will be of substantial thickness, perhaps 0.1 inch for 220-volt excitation, and it is not altogether an easy matter to get such windings down

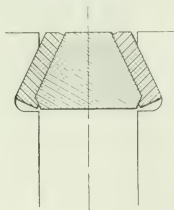


FIG. 5.

solidly in the slot in such a way that no shifting will occur during running. It must be remembered that the pressure of the coils upon the wedges in such a rotor when running at 20 per cent over speed exceeds 200 tons for each slot. As a matter of fact, it is hardly possible to put this pressure upon the winding during construction, but fortunately it seems that by a suitable succession of applications of considerable pressure, with baking processes interspersed, the further yielding of the windings with increased pressure is small, and quite good results can be obtained, even when the pressures put upon the copper during construction do not reach those which will occur during the over-speed test. Even so, special shop equipment is needed to press the windings into the slots in the way indicated above. Finally, it is important that the retaining wedge should be put into position while the coil is still under considerable pressure. This, however, is almost impossible if it is attempted to drive the wedge over the top of the coil in an end-wise direction. The wedge construction shown in Fig. 5 is very effective in overcoming this difficulty, inasmuch as the central bronze

part of the wedge can be inserted in the slot and pressed down upon the winding under great pressure while the two steel liners, one on each side, are driven into place without any friction on the top surface of the insulated coil. While this mechanical feature of the 3-part wedge is important, there are also electrical advantages. On account of the high air-gap density, the size of air-gap is small for machines of this class, being of the order of 1 inch radially. In conjunction with such an air-gap, the width of rotor slot required to accommodate a  $1\frac{3}{4}$  in. copper strip would introduce a considerable extra stator-tooth loss, due to the pulsation of flux in the tooth as the rotor slots and teeth pass underneath it. By the 3-part rotor wedge construction, the opening of the rotor slot is, from a magnetic point of view, greatly reduced, and a reasonable compromise is thereby effected. Oscillograph tests to investigate this matter have been taken, by using an exploring coil round the top of one tooth of the stator, and such records were obtained both at no load (full voltage) and under load conditions.

#### COIL-RETAINING RINGS.

As regards the part of the rotor windings external to the core, we have a very serious problem to meet in supporting this free copper. Of the methods so far used or proposed, the most satisfactory, for machines of the size considered here, is the use of a weldless chrome-nickel steel ring proportioned to carry its own load and that of the copper underneath it without any radial support from the rotor. The severe conditions to be met here may be inferred when it is recollected that this steel ring would have, due to its own weight only, and without any of the copper load which it has to support, a stress of 17,000 lb. per square inch when running at normal speed. The best properties obtainable are required for this ring, although we cannot, of course, expect to get as good characteristics in the steel of a ring of this size as we could in a small bolt. However, we can depend on getting properties at least as good as the following:—

Ultimate strength...	120,000 lb. per sq. in.
Yield point...	100,000 lb. per sq. in.
Elongation...	18 % in 2 inches
Reduction of area...	50 %

The fractures are always silky, and in most cases beautifully symmetrical cup fractures.

The importance of inspecting and testing in the case of these rings is very great, and at least four test-bars should be taken from each ring. As it is also important to obtain the most favourable forging conditions possible, the width of the ring should preferably be such that it can be accommodated in a tyre-mill, the uncertainties introduced by forging on a mandrel being thus avoided.

The rings must be positively driven by means of a key, and this is best located in the rotor body rather than in the outside end disc. In considering these details we have to provide for possible short-circuit conditions involving a considerable retardation shock to the rotor. For these reasons we make provision for driving forces of the various parts which would otherwise appear to be unnecessary.

Steel is used for the retaining rings, in spite of the electrical and magnetic difficulties which it introduces,

because in such matters the mechanical considerations must take precedence over everything else. It will, however, be noticed that the rings tend to form a magnetic short-circuit from pole to pole, and in fact they do account for a large leakage. The design of the tip of the ring, and its connection with the rotor body, are arranged to reduce this evil as far as possible, and a comparatively slight variation in this respect can make a large difference in the leakage in the case of a 4-pole rotor. The 2-pole machines of large size saturate their ring cross-section almost necessarily, and in this case the end disc, which centres the ring at its outer end, is made of manganese bronze to obviate further leakage. In the 4-pole machine this disc is made of steel, without appreciably affecting the leakage.

Some of the more obvious ways of diminishing leakage, and at the same time obtaining ventilation of the copper supported by the rings, are of a nature which seriously affects the strength of the ring, and are therefore undesirable. Any slotting of the tip of the ring which breaks the continuous circle results in so much extra dead load being put upon the ring material immediately behind the slotting; further, in the case of this alloy steel it is of the greatest importance to have fillets everywhere, and entirely to avoid any sharp corners or notches. The key-way which necessarily cuts through the tip of the ring is made as shallow as possible and is provided with good fillets. It has been the practice of some companies to use for these rings either 25 per cent nickel steel, or a manganese bronze. While both these materials have the great advantage of being non-magnetic, they also have some mechanical disadvantages, but they are feasible for small machines. For the machines under discussion there can be no question as to the advisability of using the best material from the mechanical point of view, and neutralizing the effects which are injurious from the electrical standpoint.

So long as the load on the generator is a nearly balanced 3-phase (or 2-phase) load, the objection to a magnetic end-ring is chiefly on account of the extra flux with which it burdens the rotor. It is true that the projecting stator coils to some extent overhang the steel ring, and that the leakage flux from these penetrates the ring and is increased by the presence of magnetic material there, but this flux sufficiently approximates to a rotating field of constant magnitude for comparatively small losses to appear in the rings on its account. Occasionally, however, the system of distribution from the power house is such that a balanced condition of phases cannot be obtained; in this case the leakage flux from the stator coils is no longer a simple rotating field, and very large losses would occur in the magnetic steel end-ring in consequence.

While this matter had been recognized by us for many years, it first became necessary to tackle it seriously when the problem arose of building several 4-pole, 60-period generators of nearly 20,000-k.v.a. rating which would be required to operate upon a considerably unbalanced 3-phase load. Such preliminary investigations as could be made upon a similar existing distribution system indicated that we ought to provide for unbalanced conditions equivalent to a 3-phase load of half the rated kilovolt-amperes, upon which was superposed a single-phase load of the same number of amperes. A little investigation shows that a comparatively thin sheet of drawn copper outside the ring would carry sufficient current to protect the

magnetic material below it from this stray flux. The sheet, however, would require an increased cross-section at the outer end of the ring and again at the end near the rotor body, unless the sheet could be effectively connected electrically to the slot wedges of the rotor. The difficulty of safely providing such a protective shield would be quite considerable, not to mention the liability of having trouble from it in operation. For the machines above referred to, for unbalanced-load conditions, the difficulty was overcome by dividing this sheet into a number of hard-drawn copper strips about  $3/16$  inch thick, which were driven and caulked into axial dovetailed grooves upon the surface of the ring, thus covering about 80 per cent of the entire perimeter with copper and maintaining a thoroughly substantial construction. In order to provide the copper for the circumferential path of the protecting current, dovetail grooves were turned in the chrome-nickel steel ring near its outer end; into such a groove was fitted a pair of heavy copper strips of rectangular section side by side, and by means of hydraulic pressure these strips were pressed in and made to expand and fill the dovetail section of the groove. For mechanical reasons this copper was distributed in two grooves instead of one. As it was not feasible to depend entirely upon the electrical connection of the ring with the rotor body, it was necessary to provide similarly a circumferential path at the other end of the ring, and for this purpose a short section of ring was made of manganese bronze and securely united to the chrome-nickel steel ring. In making the axial dovetail grooves to carry the copper strips, all these conducting rings were cut through at the same time as the steel, and good electrical connections obtained between the strips and the conducting rings by caulking. While the short length of manganese-bronze rings could if necessary be carried as a load by the steel ring, it was desirable to make this, so far as possible, self-supporting and to obtain the very best properties in this material. A number of experiments were required before we were able, by applying a certain amount of cold forging to the cast bronze ring, to obtain results which might almost be considered remarkable in a cast ring of such dimensions. The following figures indicate the results of tests on bars taken out of these bronze rings:—

Ultimate strength	75 to 86,000 lb. per sq. in.
Yield point	... 60 to 75,000 lb. per sq. in.
Elongation	... 12 to 15 % in 2 inches
Reduction of area	20 to 30 %

It will be noticed that in addition to this bronze ring being necessary owing to electrical considerations, we gain the magnetic advantages of having a separator between the steel ring and the rotor body. In Fig. 6 can be clearly traced the axial bars and circumferential copper rings referred to here. Some of the other features of construction already described are also evident; in particular the ventilating grooves located at the plate interfaces. The heavy-feed tool-marks on the surface of the rotor must not be mistaken for indications of the plate thickness.

It is hardly necessary to point out that the unbalanced load affects the flux conditions in the main body of the rotor also, and must be provided for by heavy longitudinal dampers. In the slotted region of the circumference, the slot wedge is used for this purpose, being made in

continuous lengths and of hard-drawn copper; elsewhere special dampers are inserted. These dampers complete their electrical circuit by means of all the circumferential copper and bronze of the end-rings; and the design of the bronze section of the ring is such as to ensure the electrical connection being improved rather than the reverse by the stresses arising upon rotation. The adequacy of this rotor protection is best illustrated by test figures. Single-phase and 3-phase short-circuit runs were made upon these machines, the power absorbed

30,000 volts. The Westinghouse Company advise that they are now building 2-pole single-phase machines of a rating 25 per cent greater than the above.

#### ROTOR COIL BRACING.

The necessity of a positive key-drive for the rotor end-rings has been indicated. In a similar way the problem of the circumferential bracing of that part of the rotor winding which is external to the core must be faced. In the case of 4-pole machines having only three heavy coils

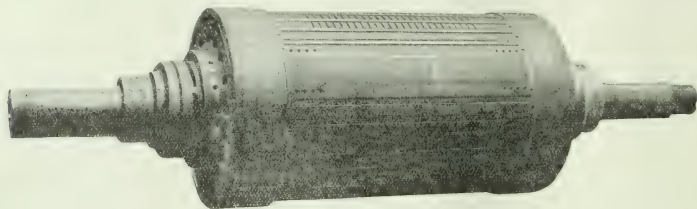


FIG. 6.

being measured, less than that due to friction and windage. This was found to be only 10 per cent greater when the machine was delivering rated current on a single-phase short-circuit than for the same current on a 3-phase short-circuit, thus indicating only a very small additional loss due to the unbalanced single-phase effect. In similar machines without this balancing device the extra power absorbed on a single-phase short-circuit is very high indeed. Perhaps it may be well to mention here that in

per pole of less than  $90^\circ$  pitch, no very special means are needed. In the case, however, of 2-pole machines where the coil-span is twice as great, and where we have of necessity more coils per pole, involving a greater length of straight extension from the slot, it is important effectively to brace the windings. A number of considerations enter into this matter, such as a possible very slight change of position of the end-windings between the stationary and full-speed conditions; also the necessity of thoroughly

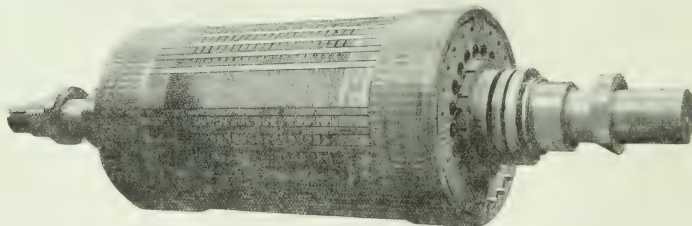


FIG. 7.

the case of turbo-generators the total loss on a short-circuit test is very great in comparison with the product of the square of the currents flowing and the resistances of the stator windings. Hence the fact that in the single-phase run only two-thirds of the winding is involved does not vitiate the excellent nature of the single-phase short-circuit results given above.

Several large 2-pole, 25-period, single-phase turbo-alternators have been constructed upon somewhat similar lines. Fig. 7 shows such a rotor for a machine of a little over 11,000-k.v.a. single-phase rating; the stators of these machines were insulated for a one-minute puncture test of

anchoring any blocking device used, and the desirability of avoiding extra centrifugal load upon the end-rings by reason of these accessory parts. In view of the nature of the effects to be guarded against, mere blocking from coil to coil will be ineffective, and we require some driving device rigidly attached to the metal of the rotor itself. Fig. 8 illustrates the system of blocking adopted for a 21,000-k.v.a., 2-pole machine in which a light built-up steel driving-horn is located on the interpole centre line of the rotor, being firmly attached to the shaft by heavy chrome-nickel steel bolts. The shaft diameter at this place is but little smaller than the inside diameter of the coils, so

that a very effective stay is obtained. With this provision made for the coils of largest span, it merely becomes necessary to block the succeeding coils from these and from one another. This is effected without departing from the principles enunciated above, by the use of a metal block carried by a radial chrome-nickel steel stud having some degree of flexibility and acting merely as a tie and anchor. Substantial insulating shoes separate the coil from the block.

#### STATOR CONSTRUCTION.

We have so far dwelt upon the difficulties of rotor construction, inasmuch as these were felt to be perhaps the hardest of solution. The electrical conditions to be met in the stator are by no means easily provided for; some of them will be briefly touched upon. Reference has already been made to the high air-gap inductions and the severe way in which the annulus of stator material in the neighbourhood of the slots must be worked. The comparatively small air-gap and considerable length of the

volumes a large central opening is necessary. This could be provided in the form of a number of vent ducts, but a large amount of resistance to the air flow would be occasioned by so much breaking up of the continuity of the axial air-passage. It becomes desirable, therefore, to attempt the equivalent of a single central opening. However, as it is not feasible to make any provision in the rotor for the absence of stator material at this place, a great concentration of flux is to be expected in the punchings immediately adjacent to and on each side of the central duct. Also, a great deal of stray flux from the rotor would enter these punchings at their face surface instead of at their edge. These conditions would be so severe as to cause prohibitive heating in this part of the stator if suitable provision were not made. This provision must be made in two ways: First, by properly proportioning the flux per inch of core immediately next to the vent; and second, by taking care of the large stray flux leaving the rotor from this vent zone. The stray flux can be

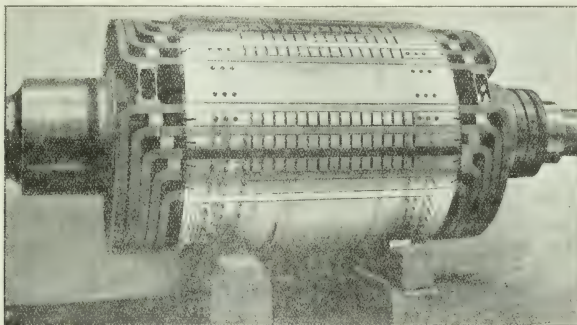


FIG. 8.

machine forbid the use of radially-disposed stator vents receiving their entire air supply from the air-gap. Some system of axial ventilation is practically imperative, and in these machines very complete axial ventilation is provided. The provision for the air supply is particularly liberal immediately behind the teeth; in fact, behind each slot are arranged three oval ventilating openings, with only a narrow strip of punching separating them from one another and from the slot; in this way the amount of core cooling surface is properly proportioned to the cross-sectional area of the vent.

On account of the length of these machines, the cooling air is admitted at each end of the stator and discharged at the centre, avoiding the considerable difference of air temperature between inlet and outlet involved when the air is passed along the entire length of the machine. This arrangement also considerably simplifies the question of rotor ventilation. The total volume of cooling air required by such a machine is in the neighbourhood of 60,000 cubic feet per minute: and in order to accommodate these

taken care of by placing a couple of packets of punchings in the centre of the vent with the teeth cut back somewhat, the thickness of the packet being properly proportioned with respect to the increased air-gap of this part of the core, so that each packet will carry a correct amount of flux. The conditions at the end of each half of the core can similarly be taken care of by cutting back the teeth in steps, so that the air-gap is graded here to allow for the fringing effect from the rotor. In some cases it is of advantage to obtain these increased air-gaps, not necessarily by an increased inter-iron space, but by removing some of the magnetic material of the teeth themselves or immediately behind the teeth.

#### EXTERNAL SHORT-CIRCUITS.

One of the great difficulties anticipated from the start in the case of these large machines was the conditions arising in the case of a feeder short-circuit or its equivalent; and much discussion has arisen with regard to the advisability of using large reactance coils between the

generators and their busbars. While a certain amount of external reactance has its use in some cases, it has been felt by some of us that these large machines should in any case be so built that they could be "dead short-circuited" at their terminals when running excited and giving full voltage. While this should be no excuse for slackening the precautions taken in the rest of the system to avoid serious short-circuits, and while repeated short-circuits at the terminals should not be countenanced, it did not appear unreasonable that a purchaser should desire to see his machine short-circuited in this way on the test-floor or after erection. The author has referred elsewhere\* to some of the characteristics of recent large machines in this respect, and has drawn attention to the fact that where these units are required it is seldom of importance to have a close inherent regulation—rather the contrary. A poor regulation and a comparatively low ratio is desirable between the excitation required for full voltage at no load, and that required for full-load current on short-circuit.

In the paper referred to above, the author indicated in a rough practical way a picture of the conditions occurring with regard to stator and rotor flux on a short-circuit. He suggested that when a short-circuit takes place across two terminals of a 3-phase machine at the instant of zero voltage between those terminals, the maximum flux is being enclosed by the short-circuited band of conductors, and that as the rotor progresses, tending to withdraw this flux, the short-circuited stator copper maintains the flux at that time encircled, whilst the rotor also—by reason of its low-resistance circuits—maintains its own flux. The enormous short-circuit stator currents and increased excitation currents, together with the circulating currents in the body of the rotor and in the slot wedges, distort these fluxes, making each complete its circuit as best it may circumferentially through the air-gap and through whatever space is found available.

It has since been possible to obtain some confirmation of these conditions from oscillograph tests on some of these large generators. Exploring coils were threaded through the stator immediately behind the slots, to test, first, the course followed by the flux encircled by the short-circuited stator copper, and secondly, that of the flux associated with the rotor. By means of two exploring coils of approximately one pole-pitch span, one of which coils has its axis coincident with the axis of the short-circuited stator copper, and the other of which has its axis displaced 90° (electrical), we can trace the action during the short-circuit. From the first exploring coil we find a normal voltage wave up to the instant of short-circuit, from which time onwards the voltage generated in the exploring coil has a very small amplitude, and such voltage as arises is clearly due to high-frequency pulsations connected with slot-pitch questions. Were there any considerable 60-period changes of flux as the successive poles pass under the short-circuited copper, this exploring coil would be bound to show a correspondingly large 60-period voltage, such as is recorded immediately before the short-circuit. The second exploring coil shows the voltage produced by the

stator flux which does not thread the short-circuited copper; in other words, it samples the rotor flux; and the oscillogram given by this exploring coil shows a continuity passing through the instant of short-circuit, the curve only gradually changing shape and amplitude after many cycles beyond the short-circuit point.

An appreciation of the general nature of these distortions arising on short-circuit is of some importance, indicating among other things the great gain that may be expected by providing what will be, from this point of view, an increased air-gap; that is to say by increasing the physical distance between the stator copper and such part of the rotor (generally very near to the surface) as is effective in carrying large currents. The author does not believe that there is much to be gained by the presence of magnetic material in the interspace between the windings; for instance, a partial closing of the stator slots by overhanging tooth-tips would not be of appreciable benefit under short-circuit conditions. The chief requirement is more space. In the machine mentioned, this increased space is obtained by a device which became necessary owing to entirely different relations; it is obtained by the use of the laminated magnetic slot-wedge described below. The results of short-circuit tests on a 20,000-k.v.a. machine with this construction showed by oscillograph tests how effectively the maximum short-circuit current had been kept down. The maximum possible short-circuit current found at full voltage, assuming the short-circuit to occur under the worst conditions of phase, amounted in this machine to only about 1.4 times the maximum of the full-load current wave. In some other machines, not requiring the laminated wedge, the desired separation has been obtained otherwise.

#### STATOR-COIL BRACING.

As regards protecting the part of the winding external to the core, the means adopted in this case are believed to be more substantial than ever before used. Fig. 9 indicates the type of stator end-winding and bracing adopted, but it does not clearly show that the supporting conditions obtaining throughout the length of the core, by reason of the teeth and slots, are again reproduced in the end windings. This is effected by means of bronze herring-bone castings placed between the two layers of the end-connection winding, the casting having fins projecting between the coils on each side of it, thus locking the two layers together and entirely providing for any tendency of the one layer of winding to shear relatively to the other. In fact, we have at every one of the 16 metal supporting brackets practically slot conditions reproduced.

#### ROTOR SURFACE LOSSES.

It has seldom been the case in the past in turbo-generator work that with reasonable design it has been necessary to pay much attention to the question of rotor-face losses occasioned by the open stator slots. With reasonable stator slots the air-gap has been generally ample, even in spite of the very great peripheral speed of the rotor. In the present case, however, with an air-gap of only about 1 inch radially and with the very high air-gap inductions involved, great caution was needed. It happened that, in the first few machines concerned, the stator voltages were sufficiently low to enable a cautious compromise to be adopted, with a size of slot that did not appear to

\* A. B. FIELD. "Operating Characteristics of Large Turbo-generators." *Transactions of the American Institute of Electrical Engineers*, vol. 31, p. 1045, 1912.

involve too great risks, such slot, however, being smaller than is desirable from an electrical point of view. However, some orders having been taken for machines of high voltage (such as 13,200 volts), it was obviously necessary to discard compromise and devise a means of using a large stator slot without serious rotor loss. In this connection it may be pointed out that, while for low peripheral speeds and machines of the type common in engine and water-wheel practice we have sufficient data to determine fairly well what will be a harmful configuration of slot, air-gap, air-gap induction, etc., we have not got these data for turbo-generator conditions. In the classical article\* of

the peripheral speed of the rotor to the 15th power; and, finally, the square root of the slot-pitch. The other quantities involved may generally be considered constant from one machine to another. While it is not possible to compare, say, an engine-driven machine with a turbo-generator on the basis of this criterion, the figure has been found to furnish some kind of guide between one machine and another of similar type.

Another group of investigators,\* having carried out experimental researches on the pole-face loss due to open slots, give the factors involved as follows:—Air-gap density to index 2.5; peripheral speed to index 1.55; ratio of slot-width to air-gap to index 1.88; square root of slot pitch. This differs from the previous one chiefly in the way in which it involves the ratio of slot to gap.

This criterion may be valuable for speeds and conditions in the neighbourhood of those corresponding to the experimental researches, but again it cannot be applied to turbo-generator conditions on a comparative basis. Also, comparing one turbo-generator with another, the relative merits on the basis of this criterion will be quite different from those on the Carter basis. There is, in fact, room for further experimental investigation on this matter at the actual high peripheral speeds, great air-gap inductions, and other relative proportions involved in recent turbo practice.

Tests were made on the completion of the first machines, in which, as mentioned above, a compromise width of stator slot was used, this width being considered to the best of our knowledge to be just on the margin of safety. These tests indicated that we were not far off in our judgment, and while we had commenced to incur some little rotor losses, which would have been serious had the slots been larger, it was not necessary to use the semi-magnetic wedges that had been prepared as a precautionary measure for these slots. For the 13,200-volt machines a built-up magnetic slot-wedge had been devised, consisting of a group of punchings assembled between little flanged brass end-plates in sections of about 3 inches in length. These wedges, which were  $1\frac{1}{2}$  inches thick in a radial direction, had a very light magnetic material bridging the slot and a large clear vent-space through the centre. The wedge was put in place in the slot, and a small fibre wedge of rectangular section driven between it and the coil. Fig. 10 shows the laminated wedge and the parts from which it is assembled. This device enabled us to use with a 1 in. air-gap a stator slot 1.62 inches wide, and a stator coil which could be constructed of desirable mechanical and electrical proportions; it saved the situation.

The problem of devising a stator conductor of the size required, and with the eddy-current losses kept down to a sufficiently small value, is not entirely easy. With the protection afforded against external flux by means of the magnetic wedge, there is no great objection to using a strip about  $\frac{1}{2}$  inch wide across the slot, and the conductor can be built up of a number of such strips in parallel. It is usually sufficient with such a winding to have the strips insulated from one another, and arranged so that at the end of the coil the conductor is turned over in such a way that the strand which in the one slot is nearest to the air-gap takes a position nearest to the bottom of the slot when it occurs

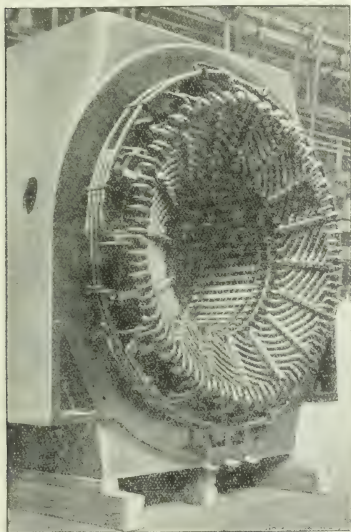


Fig. 9.

F. W. Carter, investigating the air-gap reluctance as affected by stator slots, this author proceeded to indicate in a general way the manner in which the various factors were involved which determine the pole-face loss under certain hypothetical conditions, although the formula given was probably never intended to be a quantitative indication of the pole-face loss. According to this investigation, a figure involving the following factors should be some criterion of the amount of loss per square inch:—A factor depending upon the ratio of slot to gap, which can be most easily obtained from a curve; the square of the ratio of the rotor ampere-turns for the gap to the gap length;

\* C. A. ADAMS, A. C. LANIER, C. C. POPE, and C. O. SCHOOLEY, "Pole-face Losses," *Transactions of the American Institute of Electrical Engineers*, vol. 28, p. 1133, 1909.

F. W. CARTER, "Air-gap Induction," *Electrical World and Engineer*, vol. 38, p. 884, 1901.

in the other half of the coil. It can easily be shown to what extent this transposition will avoid eddy-current losses, and that in the case of the present machine, where the total depth of the strands of each conductor amounts to 1.25 inches, there being two such conductors in the depth of the slot, and where the active length of the conductor is a large percentage of the length of the turn, this disposition is not sufficient to bring down the loss to a reasonable figure. It therefore becomes necessary to use a slightly more complicated connection at the end of the coil, the coils being connected together strand by strand, or in groups of strands, in such a way that there is a more thorough transposition of the location of the strands in the slot. Effectively we obtain the result of a much smaller

an oven and heated by independent means to temperatures very greatly in excess of any occurring in the machine, have indicated the high heat-resisting qualities of such an insulation.

Considerations such as the above, however, bring home forcibly the fact that the difficulties that we are encountering are largely connected with the size of the conductor that we have to use, and that increasing the copper section to relieve the temperature conditions tends to introduce troubles as fast as we cure them. For instance, were it possible to use, say, a fused silica tube for stator insulation, we could immediately cut down the size of the slot copper, at the same time overcoming much of our eddy-current trouble; and we should have no reason to be alarmed

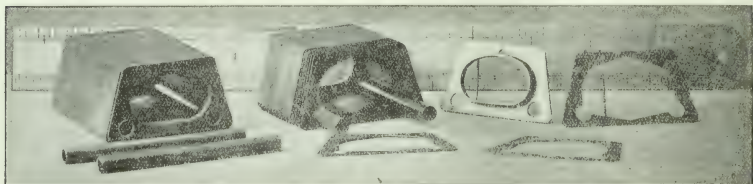


FIG. 10.

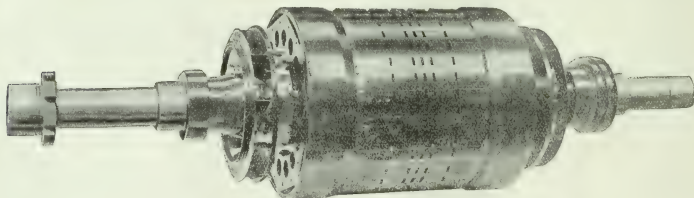


FIG. 11.

conductor with a several-circuit winding, except that this is so arranged that there is but an insignificant voltage between the several parallel conductors, avoiding the loss of space that would be entailed were we to use a multiple-circuit winding and insulate the conductors accordingly. In view of the considerable length of the machine and the somewhat severer conditions obtaining at the centre than near the ends, and also the smaller facility than usual for end-wise conduction of heat along the copper, it was considered desirable to use a stator insulation as nearly fireproof as possible, merely as a precautionary measure. For this purpose mica wrappers were applied by machine to the coil, giving an exceedingly solid insulation, having some 70 or 80 per cent of solid mica. Tests on coils insulated in this way, on a small section of core placed in

even should the central part of the active length of the conductor occasionally reach very high temperatures. The part exterior to the slot could be of twice the section or more, and the loss entailed by reason of the higher ohmic resistance of the stator winding would be entirely insignificant. Some of the characteristics of fused silica, and the recent rapid commercial development of this material, are promising as far as they go, but many obstacles to its use for this purpose remain.

In conclusion, the author acknowledges his indebtedness to the Westinghouse Electric & Manufacturing Company of Pittsburgh, without whose cordial acquiescence he would not have felt at liberty to describe these constructions. The photographs reproduced in the paper were also kindly furnished for the purpose by the Company.

## DISCUSSION BEFORE THE INSTITUTION, 25 NOVEMBER, 1915.

Professor  
Sylvanus  
Thompson.

PROFESSOR SYLVANUS P. THOMPSON: One would like to have the opportunity of examining some of these machines described by the author. Core discs without any hole through the middle, and of a thickness of  $2\frac{1}{2}$  in., we are not accustomed to deal with every day. When they are locked together so as to form a quasi-solid body one begins to wonder whether the solidity is as real as it looks. We are informed by the author that: "The rotor body as constructed consists of, first, small cross-sections (bolts) under great tension, and, secondly, comparatively large cross-sections (the plate surface around bolt holes) under compression. As long as these conditions subsist the stiffness is the same as that of a solid mass having no partition planes and it is unaffected by the stress distribution." I should like to ask the author whether that statement is an opinion of a theoretical character, founded upon experience applied to this particular case, or whether it is based on actual tests showing that the stiffness is the same as that of a solid mass. I must confess to some kind of doubt in regard to bolts that have to brace together so many joints along their length. Incidentally I should like to ask why, when the bolts are finally tightened up, the heads of the nuts are cut off. It does not seem to me to be any gain, and there might be some loss when one considers to what extraordinary tensions these bolts are subjected. When a nickel steel rod 4 in. in diameter is pulled out a visible  $1/10$  in., it is obvious that the load on the nut must be very great indeed, and I cannot see why the strength of the nut should be reduced by cutting off its head. There are undoubtedly many very interesting mechanical and electrical details. That method of constructing a wedge in three pieces, one in the middle that can be pressed down with great pressure, and then driving in the two side feathers of steel, seems to me an admirable device. The author referred to a compressible steel cell fixed upon the coil in the slot: could he give further details? In that very interesting comparison of the magnetic leakages as between a balanced 3-phase load and an unbalanced load (which is equivalent to a 3-phase load with the single-phase load superimposed upon it), we are told that the leakage is not increased more than 10 per cent, but we have no figures to tell us how much the magnitude of the leakage is. What would be the value, for example, of the Hopkinson coefficient in the case of these large machines? Some of us may remember that a year or two ago, when Professor Miles Walker read a paper bearing on the same subject,\* he explained to us—and we all smiled at the time—that the great thing in the construction of an alternator rotor was to fill the active part of the rotor with as much copper as possible, in order to get the machine well excited without too much waste, and also to fill it with iron so as to have plenty of iron to carry the magnetic flux. In other words the whole space ought to be filled with iron and also ought to be filled with copper; so that a compromise must

be made between the two. Now in this paper there is a solution of that problem of incompatibles. By avoiding the radial ventilating ducts more iron is possible than if there were no ventilating ducts, and apparently the high densities used for the current in the copper enable the copper to do more duty and so get nearer to the ideal conditions. These huge machines present very remarkable examples of the specific utilization of material, and, I suppose, tend to reduce the ultimate cost of machines in proportion to their size as well as giving us a higher plant efficiency. I wish that the author had given us a little further information about the structure by which the end bends of the stator windings are held. Fig. 9 shows very clearly those two layers of spiral end bends, like two shallow funnels one inside the other, but the author refers to a herring-bone bronze casting put between the two layers. We do not see that herring-bone casting, and want to know a little more about that apparently highly successful structure. The author has had a vision of the time when even mica will be superseded as an insulator for stator windings by some sort of fused silica. May it come soon; for the use of fused silica if it can be brought into operation—bad mechanical material as it is—will be an extremely welcome addition to the means of insulation at the disposal of the constructor. Another interesting feature is the magnetic wedge shown in Fig. 10. May I ask the author one question which is somewhat outside the ambit of the paper? The machine that is taken as typical is one for 60 cycles, a frequency of which we have had little experience in this country, although it is a standard frequency in the United States. I want to ask the author, who has had experience of these 60-cycle machines, which certainly involve more difficulties than 50-cycle machines, what is his opinion as to the advantages or disadvantages of adopting 60 cycles instead of 50 cycles as a standard. I suppose neither we nor American engineers are likely to change our respective standards. In the basement of our Institution building there is an extremely interesting alternator which possibly some of the members may not yet have seen, and which differs widely from the giants which have been described to us to-night. It is by no means a baby, for I believe it is something like 50 years old. By the side of these 30,000-h.p. monsters it is a feeble infant. I do not know how many arc lights it worked, whether one or two, but the plant efficiency must have been extremely small compared with that of our modern machines. With field magnets of the permanently magnetized horse-shoe type, and armature coils mounted on a singularly feeble barrel, to rotate in the interior, this machine affords the most striking contrast that could possibly be made between the products of electrical engineering at its best some 50 years ago and those of its most recent development to-day.

Professor  
Sylvanus  
Thompson.

MR. F. H. CLOUGH: I should like first to call attention to the rating which the author has adopted. In England this would be called a 14,000-kw. machine and would have to carry this load at 80 per cent power factor, *i.e.* it must be able to give 17,500 k.v.a., and in addition would have to carry 25 per cent overload for two hours and possibly even higher overloads for short periods. Therefore it would be

\* M. WALKER. "The Design of Turbo Field Magnets for Alternate-current Generators, with Special Reference to Large Units at High Speeds." *Journal I.E.E.*, vol. 45, p. 319, 1910.

Mr. Clough.

Mr. Clough

able to carry about 15 per cent overload continuously, which would give the same rating as the author has used, namely 20,000 k.v.a. It would be very desirable for us to adopt the same basis of rating as the author has adopted, as this rating is definite and there is no ambiguity with regard to the overloads. I believe the Electrical Sectional Committee of the Engineering Standards Committee are endeavouring to arrange this, and I hope that they will soon be able to complete their work. On reading the paper one sees the problem that the designer has been confronted with, and I appreciate very cordially the manner in which the design has been carried out and the various difficulties overcome. Especially I think the idea of putting in bolts under heavy initial tension is exceedingly ingenious. It means that the rotor material is already stressed and tending to keep the rotor rigid before any deflection takes place, or, perhaps more strictly, if a slight deflection does take place the force tending to oppose this deflection is very much greater than it would be if no initial tension were used. At the same time I think a satisfactory design could have been obtained without resorting to this construction. The author says it is impracticable to use discs with holes through them and a "through" shaft. I have only roughly attempted to calculate a machine of this rating since I received a copy of the paper, but by comparison with other similar machines actually built I am inclined to think that if the proportions of this machine were changed and the whole rotor made somewhat smaller, a through flexible shaft could have been used without having excessive stresses in any part of the rotor material. This construction would have allowed better ventilation to the rotor, and in consequence considerably more ampere-turns per pole could have been carried. We do not know what the actual flux or armature reaction of the machine is, but we are told that the rotor is saturated, and from the dimensions given we can guess the flux fairly well. Also, from the views of the stator punchings which have been shown us on the screen and the knowledge that the machine is insulated for 13,000 volts, and further from the statement that there are two layers of conductors on the armature, each  $1\frac{1}{4}$  in. deep, we can make a rational guess as to the armature reaction. Putting these figures together I feel that the machine would have been better if it had had a higher armature reaction and lower flux, especially as apparently close regulation has not been aimed at in the design; and it is probable that the author at the present time will agree with me in this, as the machine described was designed some three years ago. A re-proportioning in this way would have allowed the rotor to be rather smaller, and consequently would have reduced the mechanical stresses. The author makes a statement that if possible it is better to have the critical speed above the running speed, but at the same time admits that machines can be built quite satisfactorily which run through their critical speed. I quite agree with the author in this, but in the present instance I think that rather too great sacrifices have been made in order to obtain the high critical speed. In order to make the rotor as short as possible, fans have been omitted, so that probably external fans are necessary. This is debatable of course, but I think it is much preferable to have the ventilation of the machine self-contained rather than to have external blowing machinery, as this means so

much more auxiliary plant in the station. The rotor wedge is ingenious, but it involves three parts instead of one, and it seems to be a pity to have more separate parts on a revolving rotor than are absolutely necessary. My own experience is that it is not necessary to press the rotor coils with such heavy pressure, especially as it would seem very difficult to apply similar pressure to the end windings, and these are more liable to get out of shape than the windings in the slots. I think it is sufficient if the rotor be run up overspeed twice—once before the coils are insulated, and secondly to give the final balance. The author gives a description of the method of bracing the rotor coils. Whilst it is certainly desirable that these coils should be firmly secured in position, I do not think that the forces which come into play require such elaborate bracing as is described. The reason for this is that even if the machine is accidentally short-circuited so that a retarding force of several times the normal torque is suddenly applied, the mass of the rotor is so great that the angular retardation on the coils is comparatively small. On the other hand the centrifugal force on the coils which holds them against the retaining rings is very heavy, and this, in conjunction with the friction which necessarily exists, provides a force holding them in place, which is a great many times more than the force causing displacement. It is of course necessary to key the retaining rings so that they cannot be displaced relatively to the rotor body. In regard to single-phase losses, the paper is not clear in describing how the short-circuiting bars on the rotor are bonded at their ends, nor does there appear to be sufficient cross-section of conducting material at the ends of the rotor to deal with the aggregate current from all these rotor wedges. I am inclined to think that if this point is properly taken care of there is no necessity to go to the refinement of putting a copper damping winding on the retaining rings themselves, especially as this construction quite appreciably weakens these rings.

Mr. H. BURGE: With regard to the plate-built rotors, according to the description and the illustration in Fig. 3 the plates are recessed into one another, but except for the copper winding in the slots there appears to be no positive means of preventing the plates sliding upon one another circumferentially. It might be feared, therefore, in the event of a short-circuit occurring, that the great torsional force resulting would set up a twist in the rotor and throw it out of truth. Possibly the author can assure us on this point. It appears that one of the problems set out in the paper is to keep down the size of the rotating element in order to keep the stresses within bounds. To do this without overheating we must at least eliminate the stray losses, such as eddy currents, in the solid pole faces and in the stator conductors, which losses are so magnified in these very high-speed machines, due to the increased air-gap densities and over-saturation of the stator teeth. To this end the author has adopted the stator slot-wedges shown in Fig. 10, which must be most useful in preventing eddy currents. It is remarkable that in small machines, with an air-gap of about one-fifth of the slot width, even a light solid iron wedge will actually reduce the iron losses in the machine by 40 or 50 per cent, in spite of the fact that the pole-shoes are already laminated. As regards the eddy currents in the stator conductors, I think the most effective way, and

Mr. Burge

one which absolutely cures this trouble in deep slots, is to use a compressed stranded conductor with a solid end connection. In this way each strand completely turns over every two or three inches of the slot, and eddy currents are practically eliminated, a thorough transposition of each wire in the strand being obtained.

Dr. S. P. SMITH: The first thing to be noticed in reading the description of this construction is the difficulty which American engineers obviously feel on account of the adoption of a frequency of 60 cycles per second. In this country, where we have a standard of 50 cycles, *i.e.* a speed 20 per cent less, similar difficulties do not seem to have occurred to the same degree. The whole design seems to be governed by the question of the critical speed, in the desire to obtain a shaft of such stiffness that the running speed shall be below the critical speed. The author gives reasons why that should be so, but I should like to ask him whether he can tell us why a shaft should vibrate worse between the first and second critical speeds than below the first critical speed. Though his experience proves that this is so, it is not easy to see the reason for it, and I should very much like to have the explanation. Of course, if a rotor can be built satisfactorily to run above its first critical speed—that is, between the first and second critical speeds, like most continuous-current armatures—then it is obvious that the limit of output can be increased very considerably. On the other hand, if the running speed must be kept below the critical speed, then the limit of output will be very soon reached, and would almost seem to have been approached already with the available materials and electromagnetic loadings. It would seem, therefore, we cannot do much more, with the present restriction on running below the critical speed, and if we are going to have much larger generating sets at this speed, I think it will be found impossible to run below the critical speed. If such machines can be built safely to run above critical speed, it is obvious that we have not reached the limits of output. This mode of construction naturally arouses a certain feeling of antipathy on reading it for the first time, for it seems rather objectionable to use a built-up rotor of this type. The suggestion naturally arises whether this idea of using "through" bolts near the circumference could not be adopted with a solid rotor, either cast or forged, and so increase the factor of safety. Probably the conditions then would not be any worse than in the rotor described by the author, and it is quite possible they might be better. I should like to hear the author's opinion on that matter. There are one or two questions to ask with regard to the effect of the leakage. The author states why they use steel end-caps, and mentions the trouble that might arise due to leakage increasing the saturation in the rotor. I should like to know what experience he has had in regard to the magnitude of that effect, and if he thinks it would be considerable in a long rotor, such as the one he describes. Of course the overhang itself will produce a certain amount of saturation, so that the flux leaking from the rotor into the end-caps would probably be only a small percentage of the total. Of course with a short machine it is possible that the effect might be very considerable. It would also be interesting to know whether the author has any figure he could give us for the value of the stator leakage for such a machine. It is one of those difficult matters which every

designer meets with. It is by no means so simple to estimate the leakage of the overhang of such a machine as it is in the case of a low-speed alternator. I was very pleased indeed to find that in the author's opinion it was not desirable to rely on external reactances to safeguard the machine against external short-circuits, but to make the machine able to take care of itself. The illustrations do not show clearly whether both slip-rings are at one end or one at each end. I should think one would be put at each end. With regard to a 2-pole machine, I rather imagine this construction would be somewhat clumsy, because with two poles it would mean that with four bolts two of the bolts would come in an awkward part of the rotor. It seems to me that its application would be rather limited with large 2-pole machines. The wedge is a very ingenious idea. Apart from its complication, it certainly seems to meet the requirements. One wonders sometimes whether it is always necessary to use so much bronze for these wedges; they are very expensive because there is a big weight of metal in these keyways. It might be possible to use cast iron, when there is no out-of-balance load. The stress is chiefly compression, though there is some shearing. My experience with cast iron for rotor wedges on machines much smaller than this, but of fairly high speed, has been quite satisfactory. Cast iron is very easy to work and is certainly cheap, and it does its duty admirably in making what may be called a semi-magnetic closing for the slots, as proved by the oscillograms obtained for the flux distribution. The last point I want to mention is with respect to the bolts passing through the middle of the unslotted part of the poles; I should like to ask the author whether he has found any throttling due to that method of construction. In any case there must be a gap, however well the bolts are fitted, and when they are stressed there is certainly some reduction of area, however slight, and I should like to know whether he has had any trouble due to this, as frequently happens when a steel piece is inserted into the pole shoe of a salient-pole alternator.

Mr. W. M. MORDEY: I should like strongly to support the author in what he says on page 74 in dealing with the subject of external short-circuits. After referring to the effect of short-circuits on feeders, he says, I think with very great force, that "it has been felt by some of us that these large machines should in any case be so built that they could be dead short-circuited at their terminals when running excited and giving full voltage." He goes on to say: "It did not appear unreasonable that a purchaser should desire to see his machine short-circuited in this way on the test-floor or after erection." I think that is a practical and necessary condition which might very well be put into every specification. I know that many makers object to it, but it is a thing that was done over 20 years ago as an ordinary test, of course on much smaller machines. It is a condition which may occur in practice and is a useful test, not only for the generator but also for the engine or the turbine. The author says that the short-circuit should be made when the machine is running excited and giving full voltage. I would go further than that and say that it should be made when the machine is running with full volts and full load, because then full steam is on and full power being exerted, which is the condition that may arise in practice. The author refers at the end of that section to the satisfactory results of such a test on a

Dr. Smith.

Mr. Mordey.

machine of a certain construction, and we have seen the oscillograph results. I should like to support what he says there about the desirability of such a test.

Professor Thompson's reference to the Holmes magneto alternator, recently added to our Museum, as not being a baby, reminds me that it was with regard to that particular machine or its fellow that Faraday said to Holmes: "It is my baby but you have made a man of it."

Mr. R. LIVINGSTONE: I am somewhat surprised that during this discussion no attempt has been made to ask why we are dealing with such very large units, at any rate in this country. I think there are very few stations in this country which have a load exceeding 30,000 kw. A single generating set would not be installed in such a station; probably six 5,000-kw. machines would be used. No doubt on railway work and for certain bulk supplies we shall have 200,000-kw. to 400,000-kw. stations just as they have in the United States, but it seems to me that the time has not yet arrived in this country when we shall be forced to face the design of such machines as the author has been discussing. In the meantime we need not make use of such complicated constructions as are probably necessary for very large outputs. I should think, with the ordinary materials of construction, machines could be built of 15,000 to 20,000 kw. at 1,500 r.p.m. without very great difficulty. The only progress which we shall probably make is in the 3,000-r.p.m. machines, and we may progress there as far as the metallurgist will permit us. We are dependent on metallurgists for the limit to which we can go with output, and on nothing else. There is no real difficulty in design provided that we can obtain materials of the requisite strength. The question of making the end-bells in steel is most interesting, and I think the difficulties have been probably overestimated. When one thinks of the flux of an alternator of 100,000,000 to 150,000,000 magnetic lines, it is easy to realize that the amount of flux necessary to saturate the end-ring is comparatively small. The only disadvantage in making the end-bells of magnetic material is that the flux at the end of the machine has not the same intensity as towards the middle of the machine, i.e. there is a little unequal distribution. The same thing happens when we provide air-gaps in the centre of the machine for carrying away the heat. We get a new distribution of flux, and even such a small variation in the spacing of the radial air ducts as  $\frac{1}{2}$  in. makes quite an appreciable difference to the heating of the iron in the centre of the machine. By spacing the air ducts closer towards the centre, we can quite appreciably increase the heating at the ends of the machine, whereas usually the highest temperature is reached at the centre of the machine. The size of the conductor in machines of such large output tends of course to the production of eddy currents, and the author has already written many excellent papers on eddy currents in those large conductors. I gather that the type of conductor which was used in this machine is one which is twisted in the slot in a peculiar way; I wonder if the author could give us any information as to how the conductor is manufactured. The ordinary method of avoiding eddy currents in the conductor is to use a stranded conductor specially twisted, and this satisfactorily overcomes the difficulty, but it has the disadvantage that at the ends of the conductor there is a weak place

which requires special bracing to withstand the effects of a short-circuit. The question of ventilation of these large units is also of importance and is indeed becoming one of the most important problems in design, namely, how to get rid of the heat and how to keep every part of the machine at the same temperature. A good many engineers favour a design of machine with fans on the rotor shaft. This is a simple form of ventilation but it adds to the length of the rotor. When we reach stations of 200,000 to 400,000-kw. capacity I think the time will have come when we should install a separate plant for the ventilation of the machines in the whole station, possibly with means for cooling the air as well as washing and drying it. Another point which impressed me in connection with the rotor described was the use of magnetic steel. We are inclined to use magnetic steel for these rotors, but it is very doubtful whether it is really necessary. It will probably be found that ordinary steel, even alloy steel, will be a sufficiently good magnetic conductor and will enable us to increase the peripheral speed of the machines. The short-circuiting of a machine running at full voltage and under full steam is an interesting point and no doubt machines in general will stand this treatment, but I have noticed in connection with steam-driven sets that when short-circuited at full voltage and no load, although the speed of the set falls very slightly yet the governor levers at once open up the throttle valve, so that at the time of short-circuit the same conditions probably exist—perhaps not so severe but approaching that condition—as when the machine is short-circuited when running at full load.

Mr. R. S. ALLEN: There is just one question which I should like to ask in connection with the bolts securing the plates together. It seems to me that the method adopted for getting the tension on the bolts is rather crude—a 6-ft. spanner on the nuts at the end of a crane. Did it not occur to the author to employ a hydraulic jack in order to raise the compression up to any amount that was thought necessary, and then tighten the bolts by hand, allowing the elastic expansion of the metal to give the bolts what tension was required when the jack was removed?

Professor A. B. FIELD (in reply): Professor Thompson referred to the rotor stiffness, and asked whether our statements were based upon theoretical considerations or upon tests. I may say that we have not placed these rotors between ways, put so many hundred tons in the middle, and measured the deflection; but we have another test which is practically the same, namely, the running test. If these rotors were not approximately as stiff as we believe them to be, we should find a very low critical speed, and I think that is about the most definite test we can make. The plates are machined with faces as nearly parallel as possible, but the final tightening up of the bolts is accomplished only after the rotor has been slotted. In this way, if the plates are not absolutely parallel we have the chance of taking up the irregularity. With regard to cutting off the nuts, perhaps the description is not sufficiently clear. The rotor has to have smooth ends; in fact, when finished it looks like a solid piece, and one would not know that it was built up except for the fact that the radial vents could only be reasonably produced by such construction. In order to tighten up the nuts it is necessary to have a hexagonal elongation of the nut to get a spanner on; but that is not the working

part of the nut, and as a matter of fact it is not threaded. It is simply an extension of the nut on which the spanner can be placed.

Information was desired as to the protecting steel cell used in the rotor winding. This is merely a U-shaped cell, of the same length as the rotor body, and accurately fitting the slot; the solid-mica insulating cell fits inside the steel cell. The mica is thus protected against the abrasive action of the air at the bottom of the winding slot and where the coil spans the ventilating spaces.

With regard to the single-phase versus 3-phase effect on the end-rings, some misconception seems to have arisen. The bulk of the magnetic leakage taken by the rings represents flux entering from the rotor, and is much the same whether working 3-phase or single-phase. There is, however, some magnetic leakage produced by the rotor windings overhanging the end-rings, and while this is a much smaller feature, the losses occasioned by it are great when the machine carries a single-phase load. The construction described is primarily arranged to obviate these losses.

Professor Thompson referred to the bracing of the stator end-winding, asking for particulars of the herring-bone spacer between the two layers. This cannot be seen from Fig. 9, but the following description may suffice. Referring to the figure, in each of the 16 positions in which a clamping plate is seen with a series of bolts passing through it, there is an angle-shaped metallic bracket rigidly supporting the windings from the frame of the machine. If the outer layer of coils seen in the figure be looked upon as a right-handed involute, the lower layer would be a left-handed involute. At the crossings of these coils we have interstices through which the clamping bolts pass into the metallic angular bracket underneath. Between the two layers of coils is located the herring-bone casting referred to; this is merely a metallic strip, approximately of the width of the clamping strips seen in the figure, but with fins cast upon it, projecting between the individual coils of the winding on the upper side, and with a corresponding set of fins, to suit the left-hand involute of the lower layer of coils, projecting from its under side. The clamping bolts pass through these herring-bone castings, and the combination of parts completely prevents shearing of the two layers of the winding with respect to one another.

The question of 60 cycles versus 50 cycles is rather too large to enter upon at any length here; but I should judge that were conditions to arise involving a completely fresh start to be made in the United States, it is extremely improbable that a combination of the two frequencies, 60 and 25, would be adopted. The European combination of 50 and 25 cycles certainly seems preferable. Difficulties arise with frequency-changers, as the speeds of revolution which are common to both 60 and 25 cycles are comparatively few and wide apart. The increased speed of 60-cycle turbo-generators compared with that of 50-cycle machines has been pointed out; but, on the other hand, this is an advantage in the case of small sets and from the point of view of the steam turbine. Very large 60-cycle rotary converters are working quite satisfactorily in the States, but 50 cycles would undoubtedly be simpler from this point of view. There is a slight advantage in the matter of cost of transformers, induction motors, etc., in

the case of 60 cycles compared with 50; but the situation has arisen by eliminating a number of other frequencies and adopting the two which at one period of the development of the country had so far chiefly predominated. In some of the work in the Western States a frequency of 50 cycles is to be found, as also chiefly in South America; but in the Eastern States it never occurs.

I am glad to see that Mr. Clough has raised the question of the basis of rating, pointing out that in England continuous overloads are still required above the nominal rating of the machine. It was similarly the practice some years ago in the States to rate machines on what was called a "normal basis," corresponding to a temperature rise of 40 degrees C. The machine was also specified to run continuously at 25 per cent overload with a rise of 50 degrees, and a further requirement was specified of a 50 per cent overload for two hours with perhaps a rise of 60 degrees. This condition is unsatisfactory, and by mutual consent of operating engineers and manufacturers it was decided that a maximum safe continuous rating of the machine was in many cases a much better basis of rating. This perhaps applies more forcibly to large machines than small, because at the present time many of these large units are going into stations having also smaller equipment. As the large machines are much more economical than those already installed, the object is to run the new plant continuously at its maximum rating, and take up fluctuations in the load by connecting more or less of the smaller and less efficient sets. In some new power stations in the United States where a large number of these big sets are being installed, these conditions do not exactly hold, but the operating engineer is still interested in the maximum output which can ordinarily be safely relied upon from the individual units, and overloads beyond this are carried, when necessary, with a full realization of the conditions involved, and generally with an eye upon electrical temperature-indicating devices showing actual internal temperatures. Mr. Clough referred to the use of a through shaft as being feasible. Undoubtedly, these machines could be built with a through shaft, and in stating that this was impracticable, the author meant from a practical point of view. Using chrome-nickel steel discs, it would be possible to use a central shaft; but the advantages would be insignificant, as the size of shaft that could be used would not add to the stiffness at all, and the disadvantage and cost of the special material compared with ordinary open-hearth carbon steel would be very serious. Mr. Clough also advocated a smaller diameter and higher armature reaction, and suggested that by these changes, and the previous one, we could get a better ventilated rotor and more ampere-turns per pole. Now the question of rotor cooling and ventilation is one of the considerations that made us aim at a short rotor. It is difficult to obtain the extra axial vent area required for a lengthening rotor, and our difficulties are successively increased as we first reduce the diameter, then increase the ampere-turns, and finally use a shaft which necessitates bored discs.

The machine described is by no means a high-flux machine. Compared, for instance, with a number of machines installed not very long ago by the General Electric Company of America, it would be a decidedly high-copper machine with low flux. The ampere-con-

ductors per inch of periphery on the stator are high, and by reducing the diameter it would be almost impossible to do anything but reduce the total ampere-conductors and increase the total flux. The machine is a low-flux machine, but having high densities because it is short: that is to say, the size of the active air-gap material is small for the output, in comparison with previous machines.

With regard to external fans versus self-contained ones, the question is debatable. There is certainly some advantage in having the apparatus self-contained, particularly when generating sets are installed individually. The feeling in the States at the time these machines were put in hand was divided on the question, although many advantages were recognized by operating engineers in the separately-driven blower. I understand from recent correspondence that station engineers over there appreciate more fully now the advantages of an external fan where the exigencies of the existing station do not forbid it. In the case of large new stations the advantages are certainly accentuated. We shall not in the future see the question of ventilation arrangements taken up as an afterthought when the building has been already erected; but the question of intake and outlet air ducts will be carefully considered in the planning-out of the station, so that these features form part of the structure of the building. In modern plant the air is properly washed or filtered before being passed into the machine, and the problem of air supply is considered as a whole for the station. It is thus a distinct advantage to be able to put in two or three, or more, blowers that will supply sufficient air for the entire station. The blowers that can be accommodated upon these large rotors are further handicapped by the necessarily inefficient relations of diameter, speed, and volume of air to be handled.

Referring to the use of a 3-part rotor wedge, Mr. Clough mentions the difficulty of consolidating that part of the rotor winding external to the slots. In the case of the machine described, this was done by using a rigid steel former underneath the overhanging windings, and steel clamping plates on top of them with a large number of bolts tightening down these clamping plates upon the winding. The procedure outlined by Mr. Clough whereby the final insulation upon these exposed coil-ends is added after running hot at full speed or over-speed, has also been followed. With reference to the rotor coil-bracing, Mr. Clough very rightly draws attention to the importance of the frictional forces between the coils and their retaining rings in avoiding injurious effects due to sudden speed retardations. These forces are very effective and useful, but apply chiefly where the pressures are highest, *i.e.* to the layers of copper towards the outer periphery, and to a much smaller extent to the copper near the bottom of the slot. It appeared to us that in the case of the 2-pole machine, rotor bracing was very desirable as a feature of insurance, although in the 4-pole machine with its less severe conditions the winding was left unbraced. I cannot cite any case in which an unbraced machine has failed by reason of displacement of the rotor windings, but one or two cases come to mind of older machines, which would indicate that this effect could be looked for in unbraced 2-pole rotors. The cases referred to are those in which turbo-generators have actually twisted up their shafts under exceptional short-circuit conditions.

This indicates that although the inertia of the rotor is very great and might be expected to take care of the ordinary short-circuit, yet at any rate cases have occurred in which the proportion of the rotor inertia to that of the steam turbine is such as to allow of the very large momentary retardation of the rotor. Mr. Clough doubted the necessity of protecting the steel end-rings against the single-phase effect, and indicated that a system of dampers upon the rotor body itself would be sufficient. Undoubtedly, by supplying the rotor body alone with an effective system of dampers, a very large part of the single-phase losses would be overcome. It is not possible to say how large a proportion, inasmuch as these half-measures were not tried. But from single-phase runs upon 3-phase turbo-generators of more than one make, it is known not only that these total single-phase losses are very high, but that the heating of the steel retaining rings, on single-phase load, renders protection of these parts necessary.

Mr. Burge has referred to the possibility of plates sliding upon one another about their common axis, and indicated that possibly the copper winding in the slots prevented this effect. The chrome-nickel steel bolts which pass from end to end of the rotor surely form a much more effective key preventing this shearing effect than the copper coils. These bolts were pressed into reamed holes so that an accurate fit is obtained, and the individual plates become keyed together without any interstices at the joints. The copper coils, on the other hand, connecting plate with plate, bridge an open vent space. Reference is made to the eddy-current loss in the stator conductors, and the use of compressed stranded conductor is advocated as a complete cure. I would point out that should the stranded conductor be compressed from a concentric cable, the eddy-current losses are not completely eliminated, inasmuch as each strand takes various positions on each side of the centre line of the conductor, an outer strand moving from the extreme top to the extreme bottom of the conductor, while an inner strand always remains much nearer to the centre line. For example, in the case of such a conductor at the bottom of the slot the effect is only about as good as halving the depth of the conductor; the outer conductor of the slot benefits by the stranding very much more, and it is really the important one to consider, but the losses are not entirely eliminated. In case the conductor is formed by a complete interweaving of strands, so that every strand is treated in precisely the same way as every other, we should eliminate the eddies, assuming satisfactory insulation; but those who have had experience with pressed stranded conductors in these large machines have generally found trouble, due partly to the difficulty of making a mechanical winding with such material.

Dr. Smith refers to the increased difficulty due to the adoption of 60 cycles as compared with the European practice of 50; while this difficulty certainly arises in the case of the machines described, there seems little doubt but that outputs will be pushed to the limits of design whether for 60 or for 50 cycles, so that the same problems will arise over here. We certainly should not look upon the matter of critical speed as limiting the possible size of future sets. Where it is reasonably feasible to work below the critical speed this was suggested to be the desirable procedure; but if we eventually require

larger machines for which this condition cannot be met, then the working speed should undoubtedly be above the critical speed. Machines have already been built in the States for 30,000 kw., and a rating of 50,000 kw. has been quite seriously discussed for a speed of 750 r.p.m. It is possible that the future may see machines of this rating for a speed of 1,500 r.p.m., or even machines of larger rating, and we should not consider the output limited by such a question as that of critical speed. Dr. Smith suggests the use of through bolts near the circumference in the case of a solid rotor, whether cast or forged, for the purpose of increasing the factor of safety where some doubts are entertained as to the reliability of the material. In this I cannot agree with Dr. Smith, inasmuch as the direction in which the material is unsafe is not such that there would be any advantage in using these longitudinal bolts. A solid forging or casting is entirely adequate from the point of view of the longitudinal stresses, but the difficulties arise with regard to the radial stresses and the necessity of having radial ductility far below the surface.

With regard to the matter of magnetic leakage produced by the steel end-rings, I would say that even in a machine of the length described the flux taken by these steel rings represents an appreciable percentage; but with the construction described it is possible to provide the pole section requisite in the rotor, together with the rotor copper section that can be readily accommodated by the end-rings, without increasing the length beyond that required from consideration of the stator densities; so that the dimensions of the machine are not seriously handicapped. Information was also asked on the question of stator-coil leakage, and in this connection I am unable to give Dr. Smith the data he desires. The demagnetizing effect of the stator windings in such machines is a large proportion of the armature reaction, and therefore considerable inaccuracies arise in the determination of the actual leakage reactance from the machine characteristics. When we further try to separate out the items due to slot leakage and the like from that due to end-winding leakage, we are apt to get a result too unreliable to be quoted. The question as a whole is dealt with in the practical design without great attention to analysing the individual items. Referring to the slip-rings, I would say that both rings are at one end of the machine, which simplifies the matter mechanically. The 2-pole machine works out very nicely as regards the location of bolts, but in this case two bolts are used for each pole, and one on the interpole centre line, making six for the whole structure. Dr. Smith's suggestion of using cast iron for the rotor

wedges is worthy of careful consideration, assuming it to be used in combination with the steel side strips. Referring to the extra reluctance introduced in the pole due to a discrepancy of fit between the bolt and the plates, I would point out that the magnetic path includes, in addition to some fairly well saturated iron, two 1-in. air-gaps in the case of the 4-pole machine, and that consequently an additional air-gap of a mil or so, should it occur at the place indicated, would not affect the result within the limits of predetermination.

Referring to Mr. Livingstone's remarks, I cannot but feel that we are going to see larger generating sets used in England in the comparatively near future. Information was asked as to the arrangement of the stator conductors, and I would say that this consisted of a series of flat strips composing the individual conductor. In the type of coil here used it is common practice to carry the insulation on such individual strands throughout the length of the coil, connecting all strands together only at the beginning and end of the coil, and arranging that the top and bottom strands, etc., are transposed by the natural twist at one end of the coil. This means that a strand occupying an outer position at one part of the coil, and a bottom position in the other half of the coil, is placed in parallel with a central strand which is nearly midway down the conductor in both halves of the coil. The method adopted in the present winding was such that, following one insulated strand through the winding from a point where all are connected together to the next point at which all strands are connected together, such a strand would be found to occupy in various slots successively as nearly as possible each position; that is to say, the strands were not connected solidly together at each end of the coil, but only at each end of a certain group of coils, allowing of a sufficient number of passages along the length of the machine to give the required transposition.

Referring to the possibility of using alloy steels for the main magnetic parts, I would say that  $3\frac{1}{2}$  per cent nickel steel has been used in many machines satisfactorily; its permeability is very nearly as good as the more usual steels.

Mr. Allen suggests obtaining the requisite bolt tension by compressing the rotor structure with hydraulic jacks sufficiently to screw down the nuts comparatively lightly. A little consideration of the relative areas of cross-section of the material in tension and in compression will show what very big pressures would be needed. It would not be possible to apply the pressure in the region of one bolt only without injury to the structure by relative distortion; and applying it to the four regions simultaneously (in the case of the 4-pole machine) we should probably need some 10,000 tons, or perhaps more.

# THE WAVE-SHAPES OBTAINING WITH ALTERNATING-CURRENT GENERATORS WORKING UNDER STEADY SHORT-CIRCUIT CONDITIONS.

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## SYNOPSIS.

**Introduction:** The action of an alternator under steady short-circuit conditions.

The wave-shapes obtaining with short-circuited alternators.

(1) The ideal polyphase machine:

(a) Salient pole:

Magnetomotive force and flux-distribution curves.

The electromotive force induced in the armature conductors, and the resulting electromotive force per phase.

The armature current.

(b) Cylindrical field:

Magnetomotive force and flux-distribution curves.

The induced electromotive force and armature current.

(2) Three-phase machines:

The armature magnetomotive force; star and mesh-connected machines.

(a) Salient pole:

The variations in the flux distribution, and their effect on the induced electromotive force and current.

(b) Cylindrical rotors:

The effect of the spacing of the rotor winding upon the wave-shape of the induced electromotive force.

(c) Experimental results upon 3-phase alternators.

(3) Single-phase machines:

The pulsating armature magnetomotive force and its effects.

(a) Cylindrical rotors:

The induced electromotive force; the effect of the position of the conductor upon the wave-shape.

The current wave.

Secondary effects set up in the exciting circuit, and their influence upon the armature circuit.

(b) Salient-pole machines:

The effect of the motion of the poles upon the electromotive force due to the armature magnetomotive force.

The current wave.

(c) Experimental results upon single-phase machines.

(4) Two-phase machines:

Deviations from the ideal case;

Secondary effects set up in the exciting circuit;

Experimental results upon a 2-phase alternator.

but for a full understanding of the physical facts connected with armature reaction it is necessary to deal in detail with the subject, and to consider not only the effective values of the various entities concerned but also their wave-forms. In particular is this the case with an alternator working under short-circuit conditions, owing to the pronounced effect of the armature reaction upon the flux distribution.

So far as the present author is aware, little, if any, matter has been published which deals in detail with the wave-shapes obtaining for alternators working under steady short-circuit conditions, and the present paper is an attempt to remedy the deficiency.

*Action of an alternator on short-circuit.*—When the current on short-circuit has settled down to its steady value, the combined action of the main and armature magnetomotive forces gives rise to a magnetic flux just sufficient to induce the electromotive force necessary to establish the short-circuit current in the windings. This electromotive force serves simply to provide the impedance voltage-drop in the winding.

In the hypothetical case of an alternator winding completely devoid of impedance, the value of the steady short-circuit current would be such that the armature magnetomotive force would be exactly equal and opposite to that due to the main field windings. The presence of impedance causes the armature magnetomotive force to be somewhat reduced, and the actual short-circuit current to be less than the above hypothetical maximum value.

Speaking generally, then, the factor which largely determines the actual magnitude of the steady short-circuit current at normal excitation, is the ratio of the main field magnetomotive force to the normal full-load armature magnetomotive force. On the other hand, the maximum possible current-rush at the instant of a sudden short-circuit is dependent upon the impedance of the armature windings, and is very little affected by the normal M.M.F. ratio. The latter ratio, however, has a direct bearing upon the time taken for the current to reach its final steady value.

*Normal magnetomotive-force ratio.*—Until recent years good inherent pressure-regulation was required of most alternators, and as a result the machines were designed with relatively stiff field windings, M.M.F. ratios of  $2\frac{1}{2}$  to  $3\frac{1}{2}$  being common. To obtain the required ratio it was merely necessary to take a suitable length for the air-gap. At the present time ratios of 2 to  $2\frac{1}{2}$  are usual for small, low-speed machines.

With the development of turbo-alternators, however, it was soon found impossible to work to such high values of the M.M.F. ratio, and at the same time to produce a com-

## INTRODUCTION.

Armature reaction plays such an important part in the operation of alternators that it is not surprising it forms the subject of many technical papers. Much valuable work on the reactance of armature windings, and on the method of dealing with the armature magnetomotive force, has been published, the object in most cases having been to develop a suitable vector treatment of the subject. In practical calculations such vector treatments are invaluable;

mercial machine, owing to difficulties of rotor heating. With machines of large output, good inherent pressure-regulation is no longer essential, especially in view of the marked success achieved by the various automatic voltage regulators. M.M.F. ratios of 1.5 or less were therefore adopted for this type of machine, and it is now not unusual with machines of very large output to find ratios of unity or less. Such machines could safely carry their steady short-circuit current indefinitely without overheating.

On the other hand, with high-frequency alternators of small output, such as are used for wireless telegraphy, owing to the small pole-pitch it becomes necessary to work with a very large M.M.F. ratio, viz. from 5 to 10, or more.

**Armature impedance.**—Excepting for very small machines, the resistance of the armature winding may be neglected in terms of its reactance.

The reactance is due in part to slot leakage, and in part to the inductance of the coil-ends. Expressed as a percentage of the normal-load impedance, the reactance due to the slots will decrease directly with increasing pole-pitch, whereas that due to the coil-ends will increase, other things being equal. At the same time the percentage reactance due to the slots will be unaffected by the length of the core, since both the main flux and the leakage flux increase in the same proportion. The actual inductance of the end coils is unaffected by the core length, so that the percentage reactance due to the end coils will decrease directly with increasing core length. As a result, with machines of many poles of small pitch and relatively long cores, the slot leakage will be by far the more important, whereas for 2-pole machines of large pole-pitch and relatively short cores, the effect of the end coils may well predominate.

The percentage reactance, other things being equal, also depends upon the magnetic and electric loading constants of the machine, increasing directly with the armature magnetomotive force per centimetre of the circumference, and inversely with the mean flux density in the air-gap.

For low-speed alternators of small pole-pitch the reactance may reach a value of 15 to 20 per cent, but for many of the early turbo-alternators its value is not greater than 5 per cent. To render these machines safer in the event of a sudden short-circuit, the modern tendency is to increase the reactance by employing deep, narrow slots; in addition, the values now in use for the armature magnetomotive force per centimetre of the circumference are much in excess of the early values. The reactance of large machines, therefore, has now reached a value in the neighbourhood of 10 per cent.

So far as the final steady value of the short-circuit current is concerned, the effect of the armature reactance is generally small. Its effect, however, not only depends upon the percentage reactance, but is largely influenced by the normal M.M.F. ratio.

For machines of small reactance and small M.M.F. ratios, the short-circuit current is but little less than the hypothetical maximum value; but for machines of large reactance and large M.M.F. ratio the reactance becomes of more importance in determining the magnitude of the steady short-circuit current. In fact, for small high-frequency alternators the reactance may well be the determining factor, and the difference between the

momentary current-rush on short-circuit and its final steady value is not very marked.

Tables 1 and 2 have been drawn up to illustrate this point. The values are those which would obtain for machines with straight-line magnetization curves, and are based on the ordinary vector treatment. They thus hold good for sine functions. A boundary line has been placed so as to include the values which may be met with in practice.

Fig. 1 gives graphically the results obtained in Table 2, and shows how the reactance affects the ratio of the armature magnetomotive force to the field magnetomotive force on short-circuit for various normal M.M.F. ratios. These curves may be used for obtaining the value of

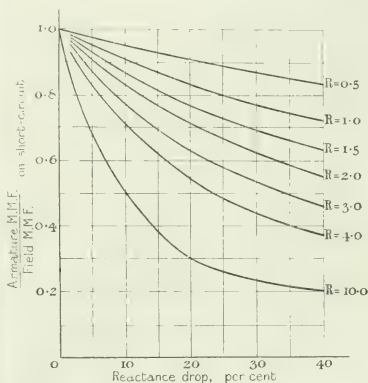


FIG. 1.—Influence of the normal M.M.F. ratio  $R$  and the reactance of the winding upon the ratio  $\frac{\text{Armature M.M.F.}}{\text{Field M.M.F.}}$  on short-circuit.

the reactance from the measured open-circuit and short-circuit characteristics. For machines which show appreciable saturation at the working point of the magnetization curve, the M.M.F. ratio for which the various curves are drawn should be taken as the ratio between the normal magnetomotive force for the air-gap on open-circuit and the normal full-load armature magnetomotive force.

In Table 1 the limiting values in the last line give a clue to the maximum possible virtual value\* of the current that can obtain at the instant of a sudden short-circuit. Actually, larger values may be experienced due to the reduction in the reactance owing to the saturation of the teeth at very high armature currents. On the other hand, reactions are often set up which reduce the current-rush.

The influence of the values of the normal M.M.F. ratio and the reactance upon the relative magnitude

\* The actual maximum instantaneous value of the current may be  $2\sqrt{2}$  times this virtual value, owing to transient effects causing the current to be shifted relatively to the zero line.

of the momentary current-rush, and the steady value finally attained by the short-circuit current, is clearly shown in Table 1.

TABLE 1.

Main M.M.F. Armature M.M.F.	Short-circuit Current at Normal Open-circuit Excitation Normal Full-load Armature Current				
	Reactance 0 per cent	Reactance 5 per cent	Reactance 10 per cent	Reactance 25 per cent	Reactance 50 per cent
0.5	0.5	0.40	0.475	0.455	0.415
1.0	1.0	0.95	0.91	0.835	0.715
1.5	1.5	1.40	1.31	1.15	0.94
2.0	2.0	1.82	1.67	1.43	1.11
3.0	3.0	2.61	2.32	1.88	1.37
4.0	4.0	3.33	2.86	2.22	1.54
10.0	10.0	6.67	5.00	3.33	2.00
Limiting value	—	20.0	10.0	5.0	2.5

\* For normal open-circuit excitation and normal full-load armature current respectively.

TABLE 2.

Main M.M.F. Armature M.M.F.	Armature M.M.F. Main M.M.F. on Short circuit				
	Reactance 0 per cent	Reactance 5 per cent	Reactance 10 per cent	Reactance 25 per cent	Reactance 50 per cent
0.5	1.0	0.98	0.95	0.91	0.83
1.0	1.0	0.95	0.91	0.835	0.715
1.5	1.0	0.935	0.875	0.795	0.635
2.0	1.0	0.91	0.835	0.715	0.555
3.0	1.0	0.87	0.77	0.63	0.455
4.0	1.0	0.83	0.715	0.55	0.385
10.0	1.0	0.67	0.50	0.30	0.20

\* For normal open-circuit excitation and normal full-load armature current respectively.

#### THE WAVE-SHAPES OBTAINING WITH ALTERNATORS UNDER STEADY SHORT-CIRCUIT CONDITIONS.

Dealing now with the various wave-shapes concerned, it is obvious that first importance is to be attached to the resulting M.M.F. distribution over the pole-pitch, since it is to this resulting magnetomotive force that the flux, electromotive forces, and currents set up on short-circuit are due. This M.M.F. distribution may be sensibly constant both in magnitude and wave-form, as in the case

of certain polyphase alternators, or it may be subject to considerable periodic variations, as in the case of single-phase machines. In addition, the wave-form will depend upon the distribution of the main exciting winding, and is thus influenced by the type of field construction, whether salient-pole or cylindrical. The following matter therefore deals with both polyphase and single-phase machines, and in each case both types of field construction are discussed.

#### (1) THE IDEAL POLYPHASE ALTERNATOR.

**Armature magnetomotive force.**—With polyphase alternators the combined effect of the currents in the various phases of the armature winding is to produce magnetomotive force fairly constant in magnitude and rotating synchronously with the main poles. Neglecting the effect of the resistance of the winding, the resulting armature magnetomotive force is in direct opposition to the main magnetomotive force. For 3-phase windings the curve of M.M.F. distribution is not of a constant shape, but the deviation from the mean sine-curve is never pronounced. With 2-phase windings the deviations are somewhat marked. The effect of these periodic variations in the armature magnetomotive force will be discussed later; for the present the ideal case of constant armature magnetomotive force of sinusoidal distribution curve will be dealt with.

#### (a) SALIENT-POLE MACHINES.

In a paper of this nature, nothing is to be gained by entering into a detailed discussion of the effects of magnetic fringing, or of the influence of the shape of the pole-shoe. It is proposed therefore to deal chiefly with the case of machines having a constant air-gap under the pole, and to neglect altogether the small field set up in the interpolar region. Moreover, the discussion is concerned chiefly with the case of the normal short-circuit test, *i.e.* with normal full-load current. Under these conditions the iron parts of the magnetic circuit are quite unsaturated, and the curve of flux distribution in the air-gap will be an exact replica of that of the M.M.F. distribution. In addition it is admissible to obtain the resulting flux distribution by summing the distribution curves obtained for the main and the armature windings when acting separately.

**Flux-distribution curves.**—With salient-pole machines the main magnetomotive force acting between the pole-shoe and the armature is constant; for the conditions assumed, therefore, the flux density under the poles will be constant, and the flux-distribution curve due to the sole action of the main winding will be of the rectangular wave-form shown in Fig. 2a. This wave may be represented by the series:

$$x = \frac{4X}{\pi} \left\{ \cos \beta \sin \theta + \frac{1}{3} \cos 3\beta \sin 3\theta + \frac{1}{5} \cos 5\beta \sin 5\theta + \dots \right\}$$

where  $\beta$  is the angle indicated, and  $X$  the value of the flux density under the pole-shoe.

The importance of the extent of the interpolar region in determining the magnitude of the various harmonics in the flux-distribution curve is thus obvious. For the  $n$ th harmonic to be zero it is necessary that  $\cos n\beta$  should equal zero. For example, with  $\beta$  equal to  $30^\circ$  the third harmonic is zero, and with  $\beta = 18^\circ$  the fifth is absent.

The flux distribution due to the sinusoidal armature magnetomotive force acting alone will obviously be of the form shown in Fig. 2*b*, the wave being represented by the series:

$$y = -Y \sin \theta + \frac{2Y}{\pi} \left( \frac{1}{3} - \frac{1}{5} \sin 2\beta \right) \sin 3\theta + \left( \frac{1}{5} \sin 2\beta - \frac{1}{7} \sin 4\beta \right) \sin 5\theta + \dots$$

The second part of the series is the equation for the portion of the sine curve that has been removed.

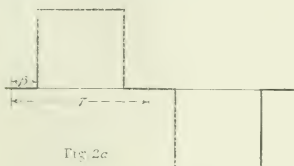
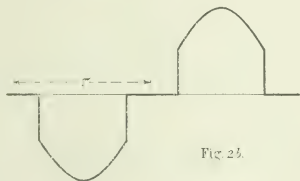

 Fig. 2*a*

 Fig. 2*b*

 Fig. 2*c*

Figs. 2*a*, 2*b*, 2*c*.—Resulting flux distribution on short-circuit for an ideal polyphase alternator; pole fringe neglected.

The resulting flux-distribution curve due to the combined action of the main and armature magnetomotive forces is obtained by summing the effects due to the separate action of the two magnetomotive forces and is shown in Fig. 2*c*. This curve is therefore represented by the series:

$$z = \frac{4X}{\pi} \left( \cos \beta \sin \theta + \frac{1}{3} \cos 3\beta \sin 3\theta + \dots \right) - Y \sin \theta + \frac{2Y}{\pi} \left( \frac{1}{3} - \frac{1}{5} \sin 2\beta \right) \sin 3\theta + \left( \frac{1}{5} \sin 2\beta - \frac{1}{7} \sin 4\beta \right) \sin 5\theta + \dots$$

The amplitude of the fundamental is thus

$$Z_1 = \frac{4X}{\pi} \cos \beta - Y \left( 1 - \frac{2}{\pi} \left( \frac{1}{3} - \frac{1}{5} \sin 2\beta \right) \right)$$

For the third harmonic the amplitude is

$$Z_3 = \frac{4X}{3} \cos 3\beta + \frac{2Y}{\pi} \left( \frac{1}{5} \sin 2\beta - \frac{1}{7} \sin 4\beta \right)$$

The relative magnitudes of the various harmonics are therefore largely dependent upon the value of the angle  $\beta$ , and hence upon the ratio of the pole-arc to the pole-pitch. In addition, the relative values of  $X$  and  $Y$  have a very important influence upon the values of the harmonics.

Dealing first with the effect of the angle  $\beta$ , the ratio of the pole-arc to the pole-pitch will generally lie between 0.6 and 0.7, 2/3 being a common value.  $\beta$  will therefore lie between  $36^\circ$  and  $27^\circ$ .

For  $\beta = 30^\circ$ , the series becomes

$$z = \frac{2X\sqrt{3}}{\pi} \left( \sin \theta - \frac{1}{5} \sin 5\theta - \frac{1}{7} \sin 7\theta + \frac{1}{11} \sin 11\theta + \dots \right) - Y + \frac{Y\sqrt{3}}{\pi} \left( \frac{\pi}{3\sqrt{3}} - 2 \right) \sin \theta + \frac{1}{4} \sin 3\theta + \frac{1}{4} \sin 5\theta + \dots$$

The amplitude of the fundamental harmonic is now

$$\frac{2X\sqrt{3}}{\pi} - Y \left( 1 - \left( \frac{1}{3} - \frac{\sqrt{3}}{2\pi} \right) \right)$$

i.e.  $1.105X - 0.945Y$ .

For the third harmonic the amplitude is

$$\frac{Y}{\pi} \cdot \frac{\sqrt{3}}{4} = 0.138Y$$

The relative values of  $X$  and  $Y$  are determined entirely by the reactance of the winding and the normal M.M.F. ratio. This has already been indicated in Table 2, which has been drawn up from the ordinary vector treatment of the subject, and therefore holds good for the fundamental harmonics of the two M.M.F. waves. In Table 2 the ratios tabulated are therefore, in the case when  $\beta$  is equal to  $30^\circ$ , not for  $Y/X$  but for  $0.945Y/1.105X$ .

Thus, considering only the fundamental harmonics of the various magnetomotive forces,

for  $\beta = 30^\circ$ ; M.M.F. ratio 2.0; and 10% reactance-drop:

$$0.945Y = 0.855 \times 1.105X = 0.942X, \\ \therefore Y = 0.975X;$$

and for an M.M.F. ratio of 1.5, and 5% reactance-drop:

$$0.945Y = 0.935 \times 1.105X = 1.04X, \\ \therefore Y = 1.10X.$$

The flux-distribution curves on short-circuit corresponding to the two above cases are shown in Fig. 3. In the latter



Fig. 3.—Flux-distribution curves for  $Y = 1.10X$ , and  $Y = 0.975X$ ; pole fringe neglected.

case it will be noted that the flux is reversed at the centre of the pole. In this case the amplitude of the fundamental is  $1.105X - 0.945 \times 1.10X = 0.065X$ , and the amplitude of the third is  $0.138 \times 1.10X = 0.152X$ . The amplitude of the third is thus 131 per cent in excess of that of the fundamental.

*Electromotive force induced in the armature conductors.*—At present, attention is being confined to the case in which both the main and armature magnetomotive forces are constant in magnitude and relative position. Under these conditions the electromotive forces induced in the various armature conductors will all have the same value and wave-shape, but will not be in phase unless situated in the same or similarly-situated slots. Moreover, the wave-shape will be exactly the same as that of the flux sweeping past the conductors. In fact, a common method of experimentally determining the flux-distribution curve is to take an oscillographic record of the electromotive force set up in a single conductor at the armature surface.

The electromotive force induced in each armature conductor will therefore have the wave-form :

$$e = \left[ \frac{4X}{\pi} \left\{ \cos \beta \sin \theta + \frac{1}{3} \cos 3\beta \sin 3\theta + \dots \right\} - Y \sin \theta \right. \\ \left. + \frac{2Y}{\pi} \left\{ (\beta - \frac{1}{2} \sin 2\beta) \sin \theta \right. \right. \\ \left. \left. + (\frac{1}{2} \sin 2\beta - \frac{1}{4} \sin 4\beta) \sin 3\theta + \dots \right\} \right] l r \times 10^{-8}.$$

The deviation from a pure sine curve is thus very marked, the third, fifth, and seventh harmonics frequently being very pronounced. Table 3 gives the amplitude of the various harmonics for  $\beta = 30^\circ$  and various values of  $Y/X$ .

TABLE 3.

*The Amplitudes of the Various Harmonics for Different Values of  $Y/X$ , and  $\beta = 30^\circ$ .*

Harmonic		Amplitude, per cent				
		$Y = 1.05X$	$Y = 1.10X$	$Y = 0.9X$	$Y = 0.85X$	$Y = 0.7X$
1	value	$0.105X$	$0.160X$	$0.255X$	$0.350X$	$0.445X$
	per cent	100%	100%	100%	100%	100%
3		13.8	86	48.5	31.5	22
5		-68	-51	-37.5	-31.5	-27.5
7		-78	-55	-37.5	-30	-25
9		-14	-9	-4.5	-3	-2.5
11		3.8	28	19.5	16	14

Fig. 4 gives the results graphically.

The value of  $Y/X$  corresponding to any particular case can be obtained from Table 2, it being remembered that the values there given hold only for the fundamental harmonics, viz.  $(4X/\pi) \cos \beta$  and  $[Y - (2Y/\pi)(\beta - \frac{1}{2} \sin 2\beta)]$  respectively. The values given in Table 2 must therefore be multiplied by the factor  $(4 \cos \beta)/(\pi - 2\beta + \sin 2\beta)$  in order to obtain the correct value of  $Y/X$ .

The relative magnitudes of the various harmonics in the E.M.F. wave set up in the armature conductors of any machine with a pole-arc equal to two-thirds of the pole-pitch can at once be obtained from the curves given in Fig. 4.

It will be noticed that the importance of the higher harmonics increases as the ratio  $Y/X$  increases. This is

due to the fact that armature reaction serves chiefly to reduce considerably the magnitude of the fundamental of the flux-wave. In addition, harmonics of the third order, although not present in the flux-wave on open circuit for  $\beta = 30^\circ$ , may be pronounced in the flux and E.M.F. waves on short-circuit. The conditions for large values of  $Y/X$  are small armature reactance and weak magnets; and for smaller values, large reactance and stiff magnets. Hence it follows that the higher harmonics will be of more importance for high-speed machines with few large poles than for low-speed alternators with many small poles.

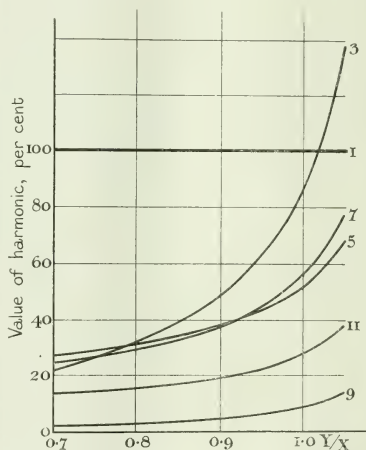


FIG. 4.—Influence of the ratio  $Y/X$  upon the value of harmonics in the flux-distribution curve for the ideal pole-phase machine on short-circuit; pole fringe neglected, and  $\beta$  taken as  $30^\circ$ .

*Resultant electromotive force per phase.*—For a mesh-connected winding with one slot per pole and phase, the total acting electromotive force per phase will be of the same wave-form as that induced in each armature conductor. If, as is usual, two or more slots per pole and phase are used, the phase displacement between the electromotive forces induced in the various slot groups will modify the wave-shape of the resulting electromotive force. This matter is dealt with in most advanced text-books, and will be but briefly discussed here. In few words it may be stated that the resultant electromotive force due to any harmonic is less than the arithmetic sum of the amplitudes set up in the individual conductors. To take account of this reduction a "distribution factor" is employed. This distribution factor depends upon the angle—in electrical degrees—between the slots, and also upon the number of slots per pole and phase. Since  $\theta$  for

the fundamental corresponds to  $n\theta$  for the  $n$ th harmonic, it follows that the distribution factors will in most cases be different for the various harmonics. Fig. 5 gives the vector diagrams for a fundamental of 100 per cent and a ninth harmonic of 50 per cent for a 2-slot winding, the slots being displaced by one-sixth of a pole-pitch and the harmonics being "in phase." The distribution factor is 0.966 for the fundamental, and  $-0.707$  for the ninth. The resulting electromotive force due to the first harmonic is displaced by  $15^\circ$  from the conductor electromotive force, whereas the displacement for the ninth is  $315^\circ$ , i.e.  $\pi + 135^\circ$ . Now  $135^\circ$  for the ninth corresponds to  $15^\circ$  for the first. Hence the ninth harmonic in the resultant electromotive force is still in phase with the first, but is reversed in sign. This reversal in sign only takes place when the angle  $n\theta$  is in the third and fourth quadrants.

The distribution factor can readily be proved to be equal to  $\frac{\sin(n s/Q \cdot \pi/2)}{s \cdot \sin(n/Q \cdot \pi/2)}$ ,  $n$  being the order of the harmonic,  $s$  the number of slots per pole per phase, and  $Q$  the total number of slots per pole.

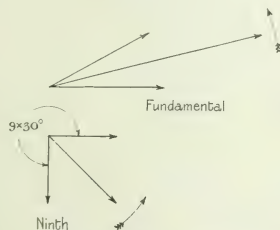


FIG. 5.—Resulting E.M.F.'s for fundamental and ninth harmonics, for  $s = 2$ ;  $Q = 6$ .

Tables 4 and 5 have been drawn up for the common cases of six and twelve slots per pole. For a given ratio of  $s/Q$ , the factors for harmonics less than the eleventh are sensibly constant if more than nine slots per pole are used.

In general, as a result of the spread of the winding, the higher harmonics are considerably reduced in comparison with the fundamental. An exception is the case of the harmonic of the order  $2Q \pm 1$ ; this exception is of little consequence owing to the harmonics being of necessity of a very high order, except in very rare cases.

Table 6 shows the amplitudes of the various harmonics for a winding in three slots displaced by  $20^\circ$ , and for  $Y/X = 1.05$ , the pole-arc being two-thirds of the pole-pitch.

Fig. 6 shows the geometrical method of obtaining the resulting E.M.F. wave-shape corresponding to the above case. It will be noticed that for this particular winding—a 3-phase mesh—the higher harmonics, and in particular the third, are of considerable importance.

In general it may be taken that the greater the spread of the winding, the greater is the relative reduction of the higher harmonics in terms of the fundamental, although there are certain unimportant exceptions to this statement.

\* For a 2-slot winding.

TABLE 4.  
Distribution Factors for  $Q = 6$ .

Order of Harmonic	$s = 2$ 3 phase Mesh	$s = 3$ 2 phase	$s = 4$ 3 phase Star or Single-phase
1	0.966	0.910	0.830
3	0.707	0.333	0
5	0.259	-0.244	-0.224
7	-0.259	-0.244	0.224
9	-0.707	0.333	0
11	-0.966	0.910	-0.836

TABLE 5.  
Distribution Factors for  $Q = 12$ .

Order of Harmonic	$s = 4$ 3 phase Mesh	$s = 6$ 2-phase	$s = 8$ 3-phase Star or Single-phase
1	0.958	0.903	0.830
3	0.654	0.307	0
5	0.205	-0.194	-0.177
7	-0.158	-0.149	0.138
9	-0.270	0.127	0
11	-0.126	0.119	-0.109

TABLE 6.  
The Resulting E.M.F. Wave for a Winding in 3 Slots displaced by  $20^\circ$ , for  $\beta = 30^\circ$  and  $Y/X = 1.05$ .

Order of Harmonic	Amplitude per Conductor	Distribution Factor	Resulting Amplitude per Conductor	
			Actual	Per cent
1	100	0.960	96.0	100
3	135	0.667	90.0	93.5
5	-68	0.217	-14.8	-15.4
7	-78	-0.177	13.8	14.4
9	-14	-0.333	4.6	4.8
11	38	-0.177	-6.7	-7.0

So far, then, it has been seen that for this ideal poly-phase alternator, the wave of electromotive force induced in the armature conductors on short-circuit contains higher harmonics of considerable amplitudes; owing to the spread of the winding, these harmonics may be greatly reduced

in importance in the wave of resulting electromotive force, but for a spread of less than half a pole-pitch the reduction is not so pronounced as to make the third, fifth, and seventh of negligible importance. Further, the relative magnitudes of the higher harmonics depend largely upon the stiffness of the main field and upon the reactance of the armature winding, and also to a certain extent upon the ratio of the pole-arc to the pole-pitch.

**Armature current.**—The wave-shape of the armature current is determined by that of the resulting electromotive force in each phase of the armature winding. It is well known that the current for each harmonic can be determined separately. On short-circuit, even for the fundamental, the reactance of the circuit is great in comparison with the resistance, hence it follows that for the higher harmonics the resistance is quite negligible.

The amplitude of the  $n$ th harmonic is therefore given by  $V_{n \max}/(2\pi n f L)$ ,  $V_{n \max}$  being the amplitude of the  $n$ th harmonic in the wave of resulting electromotive force. The

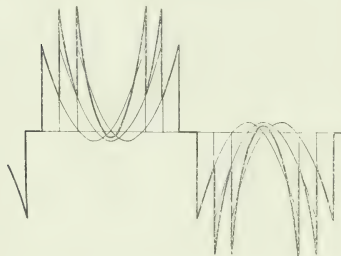


FIG. 6.—Resulting E.M.F. per phase for an ideal polyphase alternator on short-circuit, with  $s = 3$ ,  $Q = 9$ ; pole fringe neglected.

percentage amplitudes of the higher harmonics in the current are therefore reduced according to the order of the harmonic. Thus a third harmonic of 30 per cent in the resulting electromotive force gives rise to a third harmonic of 10 per cent in the current wave. At the same time the shape of the current may be considerably modified from that of the electromotive force, owing to the reversal of the "phase" of the third, seventh, eleventh, etc., harmonics. Thus an electromotive force of the form

$$e = E_1 \sin \theta + E_3 \sin 3(\theta + \psi_3) + E_5 \sin 5(\theta + \psi_5) + \dots$$

gives rise to a current of the form

$$i = \frac{1}{2\pi f L} [E_1 \sin(\theta - \pi/2) + \frac{1}{3} E_3 \sin[3(\theta + \psi_3) - \pi/2] + \dots],$$

$$\text{that is: } i = \frac{i}{2\pi f L} [E_1 \cos \theta + \frac{1}{3} E_3 \cos 3(\theta + \psi_3) + \dots],$$

$f$  being the main frequency.

As a result of this change of phase of the third harmonic a flat-topped E.M.F. wave having a pronounced third harmonic in phase with the fundamental will give rise to a pointed current wave, and vice versa.

For the case above considered, the current becomes:

Harmonic	Resulting E.M.F. Per cent	Current Per cent
1	100	100
3	93.5	-31.2
5	-15.4	3.1
7	14.4	-2.1
9	4.8	0.5
11	-7.0	0.6

The equation of the current wave is thus:

$$i = 100 \sin \theta - 31.2 \sin 3\theta - 3.1 \sin 5\theta - 2.1 \sin 7\theta + 0.5 \sin 9\theta + 0.6 \sin 11\theta + \dots$$

The harmonics higher than the third are therefore not likely to be pronounced in the current wave. Fig. 7 shows the current wave corresponding to the E.M.F. wave given

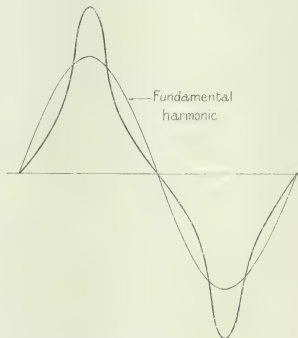


FIG. 7.—Current wave corresponding to Fig. 6.

in Fig. 6, the effect of resistance being neglected. Owing to the resistance of the winding, the lag of the current behind the electromotive force will be less than one-quarter of a period; the higher the order of the harmonic the less will be the effect of the resistance, so that the lag of the current behind the electromotive force will be slightly different for the various harmonics. The error obtained by assuming a lag of  $90^\circ$  is quite negligible, except in the case of very low reactance, and then only for the lower harmonics.

**Secondary effects.**—For the case under consideration, the armature magnetomotive force is constant, so that the main flux is constant, and no secondary effects are set up.

#### (b) CYLINDRICAL-FIELD MACHINES.

Again it is proposed to deal chiefly with the case of constant air-gap. With certain turbo-alternators the air-gap is reduced at the central portions of the pole; with such machines the behaviour is midway between that of the true cylindrical rotor, about to be considered, and that of the salient-pole machine.

With cylindrical-field systems the central portions of the poles are rarely wound, although sometimes left slotted. It is usual, too, when wide slots are used, to employ magnetic slot wedges. On normal short-circuit there is a complete absence of magnetic saturation, so that it is immaterial whether the central portions of the pole are slotted or not. For clearness, it is proposed to neglect for the present the ripples due to the exciting winding being placed in slots, and to assume that the winding is uniformly distributed over the wound portion of the rotor.

*M.M.F. distribution curves.*—Under the above conditions, the M.M.F. distribution curve due to the sole action of the exciting winding will be of the trapezium form shown in Fig. 8a, the wound portion per pole extending over an angle of  $2\beta$  electrical degrees. This wave is represented by the series

$$x = \frac{4}{\pi} \cdot \frac{X}{\beta} \left\{ \sin \beta \sin \theta + \frac{1}{9} \sin 3\beta \sin 3\theta + \frac{1}{25} \sin 5\beta \sin 5\theta + \dots \right\}.$$

Here again, as in the case of salient-pole machines, the magnitude of the higher harmonics is determined entirely by the value of the angle  $\beta$ ; the condition for the third harmonic to be absent is that  $\beta = 60^\circ$ ; and for the fifth,  $\beta = 72^\circ$ . (For salient-pole machines the corresponding values of  $\beta$  are  $30^\circ$  and  $18^\circ$  respectively.)

For the ideal case under consideration the distribution of the armature magnetomotive force is sinusoidal (Fig. 8b) and is represented by:

$$y = -Y \sin \theta.$$

The resulting M.M.F. distribution due to the combined action of the two windings will therefore be of the form shown in Fig. 8c, and corresponds to the series

$$z = \frac{4}{\pi} \cdot \frac{X}{\beta} \left\{ \sin \beta \sin \theta + \frac{1}{9} \sin 3\beta \sin 3\theta + \dots \right\} - Y \sin \theta.$$

It will be noticed that the sole effect of the armature magnetomotive force is now to reduce the amplitude of the fundamental harmonic; harmonics absent in the main M.M.F. curve cannot appear in the resulting M.M.F. distribution on short-circuit. Armature reaction therefore magnifies the effect of higher harmonics already present in the open-circuit wave, and does not introduce any fresh harmonics, as may happen with salient-pole machines.

The amplitude of the fundamental is

$$Z_1 = \frac{4}{\pi} \cdot \frac{X}{\beta} \cdot \sin \beta - Y,$$

and that of the third,

$$Z_3 = \frac{4}{\pi} \cdot \frac{X}{\beta} \cdot \frac{\sin 3\beta}{9}.$$

Taking the cases of  $\beta = 60^\circ$ , and  $\beta = 72^\circ$ , which represent the limiting values in common use; for  $\beta = 60^\circ$  the series becomes

$$z = (1.05 X - Y) \sin \theta - 0.042 X \sin 3\theta + 0.021 X \sin 7\theta + \dots$$

and for  $\beta = 72^\circ$ :

$$z = (0.915 X - Y) \sin \theta - 0.016 X \sin 3\theta + 0.0122 X \sin 7\theta + \dots$$

A common figure for the normal M.M.F. ratio of a small machine of this type is 1.5, and for the reactance pressure-drop 5 per cent. From Table 2 the ratio of the amplitudes of the fundamental harmonics of the main and armature M.M.F. waves is  $1/0.935$ .

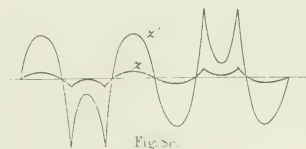
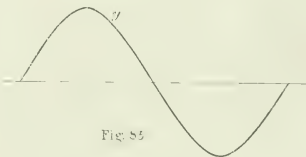
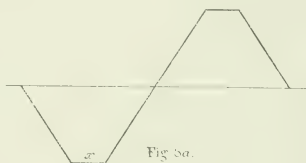
Whence for  $\beta = 72^\circ$

$$Y = 0.965 \times 0.935 X = 0.9 X.$$

The amplitude of the fundamental of the resulting wave is

$$(0.915 - 0.9) X = 0.015 X.$$

For the third harmonic the amplitude is  $0.066 X$ ; for the fifth the amplitude is zero; and for the seventh  $0.012 X$ .



FIGS. 8a, 8b, 8c.—Resulting flux distribution on short-circuit for the ideal polyphase alternator with cylindrical rotor.

In certain cases the normal M.M.F. ratio is less than 1.5, and the reactance voltage-drop less than 5 per cent, the importance of the higher harmonics being possibly much greater than is indicated by the above example. With recent machines, however, the reactance is generally in excess of the above figure.

*Flux-distribution curve.*—Since the air-gap is uniform, and the iron parts unsaturated, the wave-shape of the flux-distribution curve is an exact replica of that of the resulting magnetomotive force.

*Induced electromotive force.*—The flux distribution being constant, the wave-shape of the electromotive force induced in each armature conductor is the same as that

of the flux distribution. For the resulting electromotive force induced in the complete winding, the distribution factors of the various harmonics must be taken into account as with the salient-pole machine.

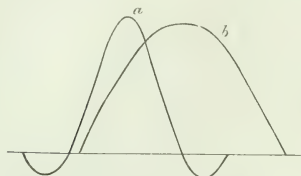


FIG. 9.—Total induced E.M.F. per phase for a polyphase alternator, with cylindrical rotor, on short-circuit.

"a" for  $s = 3$ ,  $Q = 0$ .  
"b" for  $s = 6$ ,  $Q = 0$ .

Table 7 and *a*, Fig. 9, illustrate the resulting electromotive force set up in a winding with three slots per pole displaced by  $20^\circ$ —a 3-phase mesh grouping—for  $\beta = 72^\circ$ , an M.M.F. ratio of 1.5, and a reactance drop of 5 per cent. Fig. 9, *b*, gives the resulting electromotive force with 6 slots displaced by  $20^\circ$ —a 3-phase star grouping.

TABLE 7.

Resulting Electromotive Force for a Winding with  $s = 3$ ,  $Q = 9$ ; M.M.F. ratio 1.5, Reactance Drop 5 per cent,  $\beta = 72^\circ$ .

Order of Harmonic	Amplitude per Conductor	Distribution Factor	Resulting Amplitude per Conductor	
			Actual	Per cent
1	0.065 X	0.96	0.625 X	100
3	-0.066 X	0.667	-0.044 X	-70.5
5	0	0.217	0	0
7	0.0122 X	-0.177	-0.0022 X	-3.5
9	-0.0119 X	-0.333	0.004 X	6.5
11	0.0079 X	-0.177	-0.0014 X	-2.2

**Current.**—Again the third and the fifth are the only higher harmonics likely to be of consequence; the third is absent when  $\beta = 60^\circ$ , and the fifth when  $\beta = 72^\circ$ . In general the current wave will not differ largely from that obtaining with a salient-pole machine having a similar armature winding, except in cases where the spread of the stator winding is small.

## (2) THREE-PHASE MACHINES.

The actions set up on short-circuit for 3-phase machines may be taken, for approximate purposes, as being the same as those set up in the ideal polyphase alternator just considered. However, the ideal case assumes that the armature magnetomotive force is constant and of sinu-

soidal distribution, whereas with actual 3-phase machines the magnetomotive force is neither constant nor sinusoidal, although the variations on either side of the mean sine curve are small.

**Armature magnetomotive force.**—For distributed windings, the limiting wave-shapes of the M.M.F. distribution, due to the combined action of sinusoidal currents in the three phases of the armature winding, are of the well-known forms shown in Fig. 10. As a result of these changes the flux-distribution curve will no longer be constant, but the

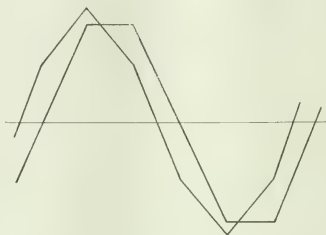


FIG. 10.—Limiting M.M.F. distribution curves for a 3-phase armature winding, assuming sine currents.

actual change in the total magnetic flux per pole is very small. The fluctuations in the armature magnetomotive force at various points under the pole may further give rise to eddy currents in the pole-shoes, which currents would produce a magnetomotive force tending to limit the extent of the fluctuations in the flux distribution. Under favourable conditions the eddy currents would reduce the flux fluctuations to a negligible amount. Should this be

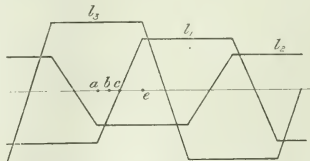


FIG. 11.—M.M.F. diagrams for 3-phase winding.

the case, the action of the 3-phase machine would correspond almost exactly to that of the ideal polyphase alternator.

With laminated pole-shoes the damping action is negligible, and for the present such will be assumed to be the case.

The armature magnetomotive force no longer being constant, the resulting flux distribution will be subjected to periodic variations, and hence the curve of induced electromotive force can no longer be obtained as hitherto. In addition, the wave-shape of the electromotive forces induced in the various armature conductors will not be

constant, but will depend entirely upon the situation of the conductor. It becomes necessary, then, to determine the manner in which the total armature magnetomotive force varies during a complete period at different points on the armature surface.

Fig. 11 represents the M.M.F. distribution for each of the three phases of the armature winding due to currents flowing in the same direction in each phase. For clearness, the windings have been assumed to be uniformly distributed, and not placed in slots, and the currents are of different values for the three phases. The height of the trapezium is in each case given by the product of the number of turns per pole and the current. The actual resulting magnetomotive force at any point is given by the sum of the effects of the three phases considered separately. At points such as *a* the three phases are fully active, and for such points as *b* one of the phases has no effect. Taking now the case of 3-phase currents in the windings; let *N* be the number of turns per pole and phase, and  $i_1$ ,  $i_2$ , and  $i_3$ , the actual instantaneous values of the currents in the three phases.

Then the total M.M.F. at  $a = N i_3 - N i_2 - N i_1$ ,  
and at  $b = N i_3 - N i_2 - \frac{1}{2} N i_1$ ,  
at  $c = N i_3 - N i_2$ .

If the wave-shape of the current is known it is therefore simple to obtain the manner in which the resulting armature magnetomotive force varies at any point on the armature surface. It will be noticed that the complete cycle of changes will take place between the points *a* and *c*, and that the limiting values occur at *a* and *c*.

In most cases 3-phase alternators are star connected, and the third harmonic is perforce absent. In addition, with such connections the spread of the total winding between terminals is two-thirds of a pole-pitch, and the distribution factors for the higher harmonics are very reduced. As a result, for star-connected machines the higher harmonics in the current wave are of negligible importance.

**Star-connected machines.**—The armature current being sinusoidal it follows that the resulting armature magnetomotive force at every point of the armature surface must also be sinusoidal, since it is the sum of three sine functions of the same frequency. Further, for 3-phase sine currents

$$i_1 + i_2 + i_3 = 0.$$

Hence the maximum armature M.M.F.  $\{ = N(i_1 - i_2 - i_3) \}$   
as at *a*  $\{ = 2 N i_1 \}$ .

The resulting armature magnetomotive force at such points as *a* is therefore sinusoidal, and of amplitude  $2 N I_{\max}$ , being the maximum value of the current in the windings).

The minimum armature magnetomotive force

$$= N(i_3 - i_2),$$

and is therefore sinusoidal, and of amplitude

$$= \sqrt{3} N I_{\max}.$$

At the mean point *b* the armature magnetomotive force  $= N(i_3 - i_2 - i_1/2)$ , and is sinusoidal of amplitude

$$\sqrt{3} \cdot 25 N I_{\max} = 1 \cdot 805 N I_{\max}.$$

**Mesh-connected machines.**—With mesh connections the spread of the winding is only one-third of a pole-pitch, and the higher harmonics, in particular the third, may be of considerable importance in the current wave.

Let the currents be of the form

$$\begin{aligned} i_1 &= I_1 \sin \theta + I_3 \sin 3\theta + I_5 \sin 5\theta + \dots, \\ i_2 &= I_1 \sin (\theta + 120^\circ) + I_3 \sin 3(\theta + 120^\circ) \\ &\quad + I_5 \sin 5(\theta + 120^\circ) + \dots, \\ i_3 &= I_1 \sin (\theta + 240^\circ) + I_3 \sin 3(\theta + 240^\circ) \\ &\quad + I_5 \sin 5(\theta + 240^\circ) + \dots \end{aligned}$$

Then the resulting magnetomotive force at such points as *a* is

$$N \{ 2 I_1 \sin \theta - I_3 \sin 3\theta + 2 I_5 \sin 5\theta + \dots \}.$$

The resulting magnetomotive force at the mean point *b* is

$$N \{ 1 \cdot 805 I_1 \sin (\theta - 13 \cdot 6^\circ) - 0 \cdot 5 \sin 3\theta + 1 \cdot 805 I_5 \sin 5(\theta - 13 \cdot 6^\circ) + \dots \}$$

For such points as *c* the resulting magnetomotive force is

$$N \sqrt{3} \{ I_1 \sin (\theta - 30^\circ) - I_3 \sin 5(\theta - 30^\circ) + I_5 \sin 7(\theta - 30^\circ) + \dots \}.$$

The harmonics higher than the third are of negligible importance. For the third, at such points as *c* the third is non-existent; at *b* the amplitude is  $0 \cdot 5 N I_3$ ; at *a* the amplitude is  $N I_3$ .

The mean amplitude of the third harmonic in the wave of resulting armature magnetomotive force is thus  $0 \cdot 5 N I_3$ , as compared with  $1 \cdot 81 N I_1$  for the fundamental harmonic. Thus for the case already given of  $Y/X = 1 \cdot 05$ , in which the third harmonic is exceptionally prominent in the current wave (31 per cent of the fundamental), its effective amplitude in the armature M.M.F. wave is only 11 per cent of that of the fundamental. For normal cases with salient-pole machines  $Y/X$  is approximately  $0 \cdot 95$ , the third harmonic in the current is considerably reduced, and its effect upon the M.M.F. distribution is negligible.

#### (a) SALIENT-POLE MACHINES.

**Flux distribution.**—Under the conditions previously assumed the flux distribution will vary periodically at



FIG. 12.—Limiting flux-distribution curves for 3-phase alternator on short-circuit.

six times the main frequency, and the limiting shapes will be as shown in Fig. 12.

**Induced electromotive force.**—As a result of the fluctuations in the resulting armature magnetomotive force, the electromotive force set up in the armature conductors will depend to a certain extent upon the position of the con-

ductor. The electromotive force induced in any particular conductor may be taken as being composed of two parts:

- (1) An electromotive force of constant magnitude and wave-shape due to the mean value of the total resulting magnetomotive force, and
- (2) An electromotive force due to the additional magnetomotive force which alternates at six times the main frequency.

Assuming that the variations in the resulting magnetomotive force follow a sinusoidal law, the electromotive force due to these variations will give rise to ripples in the wave of total electromotive force set up in the conductor, the ripples being equivalent to the combined effects of harmonics of the  $(6 - 1)$ th and the  $(6 + 1)$ th orders, i.e. the fifth and seventh. The amplitude of this ripple will not be the same for all the conductors but will depend upon their position; in no case, however, will the amplitude be large.

The effect of this ripple will be chiefly noticeable when the conductor is in the interpolar space, i.e. in the zero region of the E.M.F. wave; it will also cause the dip in the wave of induced electromotive force to be more pronounced for the positions at which the search coil is subjected to the maximum variations of the pulsations of the flux.

The eddy currents induced in the pole-shoes by this alternating component of the flux render the already small

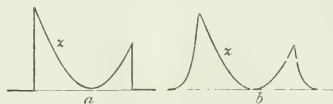


FIG. 13.—Effect of armature resistance and fringing upon the shape of the resulting induced E.M.F.

deviations between the general action of a 3-phase alternator from that of the ideal polyphase machine practically negligible.

The total electromotive force induced in the winding is the sum of the conductor electromotive forces, and it is obvious that no appreciable error will result from considering the electromotive forces induced in the conductors to be of the constant wave-form corresponding to that of the conductors situated—as at *b*—midway between the limiting positions.

As a result, the total induced electromotive force and current waves for 3-phase star-connected alternators will not differ appreciably from those obtaining with the ideal polyphase machine having a winding of similar spread. For mesh-connected machines, the presence of the third harmonic in the current wave may cause slight differences from the ideal machine, but these will be trifling. The chief difference between the star- and the mesh-connected machines will be that the third harmonic will be absent from the current for the star, and probably present for the mesh winding.

*Effects of armature resistance and fringing.*—So far as resistance is concerned, the effect is simply to cause the lag of the current behind the induced electromotive force to be less than one-quarter of a period, and as a result the arma-

ture magnetomotive force will not be in exact opposition to the main magnetomotive force. A slight dissymmetry in the wave-shape of the induced electromotive force is thus produced. Neglecting the flux in the interpolar space, the wave-shape would then be as shown in Fig. 13*a*; including the flux due to fringing, the induced electromotive force will then be of the form shown in Fig. 13*b*. So far as the total electromotive force is concerned, the effect of the pole fringe will be to round off all the sharp points in the curves (Figs. 6 and 9).

#### (b) CYLINDRICAL-FIELD MACHINES.

As with salient-pole machines, the departures from the conditions obtaining with the ideal case are negligible for star-connected machines, for which the short-circuit current is practically a pure sine-wave. For mesh-connected machines the third and fifth harmonics may be pronounced in the wave of resulting electromotive force, depending upon the value of  $\beta$ , and may be of importance in the current. The reactance and normal M.M.F. ratio for machines of this type are always small, and the higher harmonics prominent in consequence.

*Effect of the spacing of the rotor winding.*—The actual M.M.F. distribution due to the exciting winding is stepped, and not a straight line, owing to the winding not being uniformly distributed over the wound portion but placed

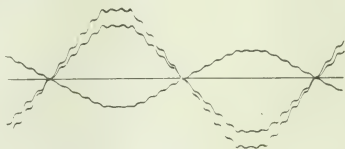


FIG. 14.—Induced E.M.F. per conductor for an unsaturated cylindrical-field alternator on open circuit.

in slots. Fig. 14 illustrates the actual electromotive force induced in a single armature conductor due to the main exciting winding, the iron parts being quite unsaturated; the curve is taken from an actual oscillogram. As a result of the main M.M.F. diagram being stepped, marked ripples are set up in the wave of electromotive force induced in the armature conductors on short-circuit. The ripples are very prominent owing to the great reduction which takes place in the fundamental harmonic of the main magnetomotive force on short-circuit, whereas the higher harmonics are not reduced to any appreciable extent. Fig. 15 illustrates the actual conditions that are likely to exist, neglecting the effect of armature resistance. Smaller ripples due to the armature slots may also be set up in these machines as in the case of salient-pole machines, but they are rarely of importance.

For clearness of construction Fig. 15 has been drawn for a smaller ratio of  $Y/X$  than is customary with cylindrical-field machines. Table 8 has therefore been prepared showing the method of calculating the resulting E.M.F. wave. The second column gives the value  $x$  due to the sole action of the main magnetomotive force; the third column gives the corresponding value of  $y$  due to

the sole action of the sinusoidal armature magnetomotive force, and the fourth column shows the value  $z$  due to the combined effects of the two magnetomotive forces. The case taken is for  $Y = 1.0$ , and  $X = 1.04$ , the rotor winding being distributed in 8 slots per pole, and two slots per pole being left vacant or the equivalent portion of the rotor not slotted. The importance of the higher harmonics in

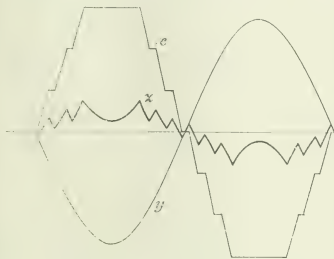


FIG. 15.—Effect of the spacing of the excitation winding upon the shape of the induced E.M.F. wave.

this case is very marked, the ripples due to the spacing of the rotor winding being particularly prominent. The resulting wave-shape corresponding to Table 8 is shown in Fig. 21a.

TABLE 8.

Resulting Flux Distribution for a Cylindrical Rotor with 10 slots per pole, of which 8 are wound.

$$Y = 1.0; X = 1.04.$$

Angle	$e$	$x$	$y$
0°	0	0	0
4.5°	0	-0.0785	-0.0785
13.5°	0.26	-0.2334	-0.0366
22.5°	0.26	-0.3827	-0.1227
31.5°	0.52	-0.5225	-0.0025
40.5°	0.52	-0.6494	-0.1294
49.5°	0.78	-0.7604	0.0190
58.5°	0.78	-0.8526	-0.0720
67.5°	1.04	-0.9239	0.1161
76.5°	1.04	-0.9724	0.0676
85.5°	1.04	-0.9069	0.0431
90.0°	1.04	-1.0000	0.0400

*Secondary effects set up in 3-phase machines.*—With 3-phase alternators the actual variation in the total magnetic flux per pole is so small that no appreciable effect upon the exciting circuit takes place.

#### EXPERIMENTAL RESULTS.

The various oscillographic records used to illustrate the present paper were obtained a few years back by the author and by other assistants in the alternating-current department of Messrs. Siemens Brothers Dynamo Works, Limited, Stafford, during routine tests carried out at the

instigation of Mr. W. Marden, the head of the department. The tests were not carried out for the purpose of this paper, so that the series of tests is not quite so complete as the author would wish, but nevertheless it is amply sufficient to corroborate the theory here put forward. For permission to use the records the author is much indebted to Messrs. Siemens, and in particular to Mr. Marden.

The oscillographic records were taken during short-circuit tests at normal full-load current, and included in each case the wave-shape of:—

- (1) The electromotive force induced in a search wire placed axially along the armature surface;
- (2) The armature current;
- (3) The exciting current;
- (4) The potential difference between the excitation slip-rings of the alternator.

It is to be regretted that no record was taken of the position of the search wire. The machines were all star connected, and no tests for mesh-connected machines are at the author's disposal. In all cases the four records were taken on the same film by means of separate exposures. The records, then, simply give the wave-shapes and not the relative phases of the various functions. The wave-shapes of the electromotive forces and currents are numbered to correspond with the above list.

#### REMARKS ON THE EXPERIMENTAL RESULTS—3-PHASE ALTERNATORS.

##### (a) SALIENT-POLE MACHINES. (FIG. 16.)

(1) *Electromotive force induced in the search coil.*—Although the search wire was placed haphazard, the wave-shapes obtained are similar for the three machines. With machine A the wave-shape is exactly as predicted for the ideal polyphase machine; whilst with the other two machines the effect of the pulsations in the armature magnetomotive force are discernible in the slight ripples set up in the electromotive force when the conductor is situated in the interpolar space. Small ripples due to the effect of the stator teeth are also noticeable.

The analyses of these E.M.F. waves are as follows:—

*Machine A:—*

$$e = 100 \sin \theta + 1.31 \sin 3(\theta + 33^\circ) \\ - 57 \sin 5(\theta - 19.5^\circ) - 47 \sin 7(\theta - 11.5^\circ) + \dots$$

*Machine B:—*

$$e = 100 \sin \theta + 7.8 \sin 3(\theta + 18.5^\circ) \\ - 23 \sin 5(\theta - 11^\circ) + 63 \sin 7(\theta - 11^\circ) + \dots$$

*and Machine C:—*

$$e = 100 \sin \theta + 170 \sin 3(\theta - 24.5^\circ) \\ - 30 \sin 5(\theta + 12^\circ) - 69 \sin 7(\theta + 8.5^\circ) + \dots$$

All machines had approximately the same designed M.M.F. ratio. Machines A and C had open slots, whereas B had semiclosed slots and fewer slots per pole than the other machines. As a result the reactance of machine B was greater than that of the other machines, and the effect of the armature currents is therefore less pronounced. This results in a considerable reduction in the importance of the third harmonic.

(2) *Armature current*.—Except for the presence of small ripples of a high order the current is in every case practically a pure sine curve. A slight dissymmetry is apparent in machine C.

(3) *Pressure between excitation slip-rings*.—No evidence of an electromotive force of six times the normal frequency can be detected; the fluctuations in the exciting pressure can in every case be attributed to the normal fluctuations in the voltage of the exciter.

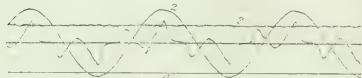


FIG. 16a.—Machine A.

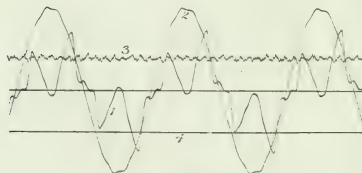


FIG. 16b.—Machine B.



FIG. 16c.—Machine C.

FIGS. 16a, 16b, 16c.—Short-circuit waves on 3-phase salient-pole alternators.

(4) *Exciting current*.—The high-frequency fluctuations present in the exciting pressure do not produce any appreciable effect upon the exciting current, which is quite constant for machines A and B. For machine C a very slight periodic variation of the main frequency is apparent. This is due to some dissymmetry in the machine, and is not a normal effect.

#### (b) CYLINDRICAL ROTORS. (FIG. 17.)

(1) *Electromotive force induced in the search coil*.—The great effect of the armature magnetomotive force upon the flux is made obvious by the importance now gained by the ripples due to the spacing of the rotor winding. As already pointed out, the reactance of machines of this type is small, and the ratio of the normal excitation magnetomotive force to the normal armature magnetomotive force is low; as a result the fundamental harmonic of the

armature magnetomotive force is but slightly smaller than that of the main magnetomotive force. With both machines the wave-shapes are of the same type and correspond exactly with the shape predicted. For machine E the position of the search wire is such that the wave is not quite symmetrical.

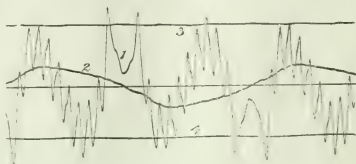


FIG. 17a.—Machine F.

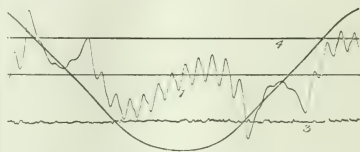


FIG. 17b.—Machine E.

FIGS. 17a, 17b.—Short-circuit waves on 3-phase alternators with cylindrical rotors.

The relative amplitudes of the various harmonics for the two E.M.F. waves are as follows:—

Harmonic	1	3	5	7	9
Machine E ...	100	163	45	26	22
Machine F ...	100	375	132	73	110

Machine F had a much smaller M.M.F. ratio than machine E, and in addition a smaller reactance.

The analysis of the curves shows the striking manner in which the importance of the higher harmonics is increased owing to the great reduction in the value of the fundamental.

The effect of the stator teeth can be detected, but is small.

(2) *Armature current*.—Normally the current obtained for this type of machine under short-circuit conditions is similar to that obtained for machine E. The wave obtained for machine F is abnormal, containing a third harmonic, and it is probable that it is not the real current curve, but that there has been some error in making the test.

(3) and (4) *Exciting pressure and current*.—These are both constant.

The results obtained with both types of 3-phase machines are in complete agreement with the predicted waves.

## (3) SINGLE-PHASE MACHINES.

With single-phase alternators the armature magnetomotive force is alternating, and not rotating, so that the flux distribution on short-circuit is no longer constant. As a result of the periodic changes set up in the flux distribution under the poles, eddy currents may be set up in the pole-shoes and damping coils—if present—and the magnetomotive force due to these eddy currents will tend to limit the changes in the flux, and under favourable conditions will reduce them to a negligible quantity. In addition to these eddy currents, alternating electromotive forces and currents may be induced in the main exciting winding, due in general to variations in the total value of the flux and not to local changes in its intensity.

These secondary effects will obviously have an effect upon the E.M.F. and current waves. With perfect damping the case will not differ appreciably from that of the ideal polyphase machine already considered. When the secondary effects, however, exert a negligible damping

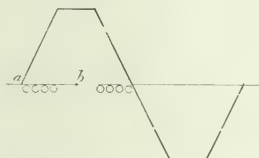


FIG. 18. The M.M.F. distribution curve for a single-phase armature.

influence, the resulting magnetomotive force is simply due to the joint action of the main and armature magnetomotive forces, the main magnetomotive forces being constant. In the following discussion the secondary effects are at first assumed to be negligible.

**Armature magnetomotive force.**—With a single-phase machine the distribution of the armature magnetomotive force is of the wave-form shown in Fig. 19, the winding being assumed to be uniformly distributed over the wound portion of the armature and not placed in slots. The diagram is an M.M.F.-space diagram, the amplitude of which varies periodically with the value of the armature current. Thus at every point of the armature surface the M.M.F. variation due to the sole action of the armature current will be of exactly the same wave-shape as the current but of varying amplitude. This latter will be maximum at the unwound part of the armature, and zero at the mid-points between the armature coils. The resulting magnetomotive force and flux distribution will not be constant but will vary between the limiting forms shown in Figs. 19a and 19b which are for salient-pole and cylindrical rotors respectively.

**Induced electromotive force.**—The flux distribution under the pole no longer being constant, the induced electromotive force in any given conductor can no longer be obtained by considering the manner in which the flux density varies at its position. For instance, the electromotive force induced by the sole action of the armature current is a minimum at the centre of the coil where the magnetomotive force and flux density are a maximum, and

it is a maximum for the outermost conductors, at which the magnetomotive force is practically zero. To obtain the induced electromotive force it is best then to consider separately the effects of the main and armature magnetomotive forces—a method rendered admissible by the absence of magnetic saturation.

The total electromotive force induced in any conductor on the armature surface is thus composed of :

- (1) A dynamic electromotive force due to the rotation of the flux set up by the sole action of the main magnetomotive force, and
- (2) A static electromotive force due to the alternations of the flux set up by the sole action of the armature current.

Of these electromotive forces the dynamic electromotive force has the same value and wave-shape for all positions of



FIG. 19a.—Limiting flux-distribution curves for single-phase salient-pole alternator, on short-circuit; secondary actions and pole fringe neglected.



FIG. 19b.—Limiting flux-distribution curves for single-phase alternator with cylindrical rotor, on short-circuit; secondary actions neglected.

the conductor, but its phase is entirely dependent upon the position. The static electromotive force, on the other hand, is in phase for all positions of the conductor, but varies in magnitude according to the position, being a maximum at such positions as *a*, and zero at *b*. For a cylindrical-field system, the wave-shape of the static electromotive force is the same for all the conductors, but for a salient-pole machine it is somewhat dependent upon the situation of the conductor.

Neglecting the slight effect of armature resistance, the static and dynamic electromotive forces are in exact opposition of phase for conductors situated as at *a*, and at quarter centres for those at *b*.

With salient-pole machines the motion of the poles causes periodic variations in the path of the armature flux, and complicates the problem to a certain extent; cylindrical rotors, therefore, will be first considered.

## (a) CYLINDRICAL-FIELD MACHINES.

As with polyphase machines, the rotor is assumed to be uniformly slotted, and the air-gap constant.

The dynamic electromotive force has the same wave-form as the main M.M.F. distribution curve, and is of the form (Fig. 18) already discussed. Fig. 20a shows the dynamic electromotive force induced in four conductors equally spaced at  $30^\circ$  from  $a$  to  $b$ .

The static electromotive force is of the same wave-shape and in phase for all the conductors, independent of their position, but its amplitude varies according to the maximum value of the flux embraced by the search coil. It is immaterial whether the coil is assumed to consist of a ring coil or of a drum coil spanning one pole-pitch.

If the current is sinusoidal the induced static electromotive force will also be sinusoidal—neglecting magnetic saturation, etc.—but for non-sinusoidal currents the wave-

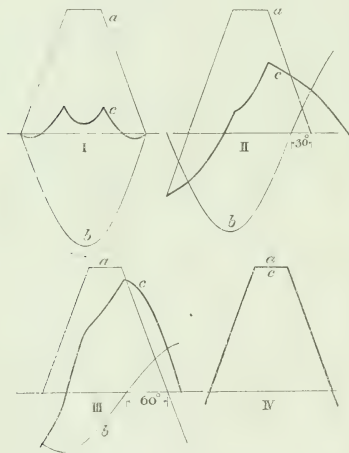


FIG. 20.—Resulting E.M.F. in 4 search wires, at  $30^\circ$ , for a single-phase alternator on short-circuit, with cylindrical rotor, surface wound; secondary effects neglected.

shape of the induced electromotive force will differ considerably from that of the current. If the current wave is of the form

$$i = I_1 \sin \theta + I_3 \sin 3(\theta + \psi_3) + I_5 \sin 5(\theta + \psi_5) + \dots,$$

then the flux will also be of the same wave-shape, and the induced electromotive force will have the form

$$e = k [I_1 \cos \theta + 3 I_3 \cos 3(\theta + \psi_3) + 5 I_5 \cos 5(\theta + \psi_5) + \dots].$$

The higher harmonics are thus far more prominent in the electromotive force than in the current wave. Moreover, the phase of the third, seventh, eleventh, etc., harmonics is reversed in the E.M.F. wave from that obtaining for the current. As a result a flat-topped current wave having a pronounced third harmonic in phase with the fundamental

will give rise to a peaked E.M.F. wave, and vice versa (see Figs. 6 and 7).

In Fig. 20,  $b$ , are shown the static electromotive forces induced in the various conductors and corresponding to the dynamic electromotive forces shown in  $a$ , Fig. 20, sine currents being assumed.

The resulting electromotive force due to the combined action of the main and armature magnetomotive forces for the various conductors considered is shown in  $c$ , Fig. 20. A very considerable variation in wave-shape thus exists for the various conductors.

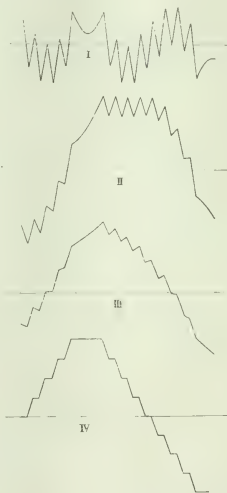


FIG. 21.—Calculated induced E.M.F. in 4 search wires placed at  $30^\circ$ , for a single-phase alternator with a cylindrical rotor.

Fig. 21 shows the actual E.M.F. waves, taking into account the spacing of the rotor winding, the curves having been calculated as indicated in Table 8.

The total electromotive force set up in the complete winding is the sum of the conductor electromotive forces. Owing to the spread of the winding, the importance of the higher harmonics in the dynamic component of the electromotive force is largely reduced, but with the static electromotive force there is no reduction whatever, there being no phase difference between the electromotive forces induced in the various conductors. This fact renders it possible for harmonics of the third order, due to secondary actions, to be present in the current on short-circuit for all single-phase machines, including alternators having a two-thirds stator winding, for which case the winding factor of the third harmonic of the dynamic electromotive force is zero. Neglecting secondary actions, however, the wave-

shapes of the total induced electromotive forces and currents for a single-phase machine with cylindrical-field system will not differ to a marked extent from those obtaining with similar 3-phase machines. The relative magnitude of the various harmonics will depend upon the spread of both the stator and field windings, and for a normal stator winding having a spread of two-thirds or three-quarters, the higher harmonics in the current wave will be of negligible importance.

#### (b) SALIENT-POLE MACHINES.

With salient-pole machines the rotation of the poles gives rise to periodic changes in the reluctance of the path

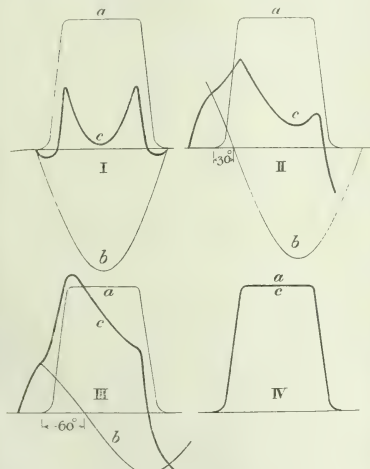


FIG. 22.—E.M.F.'s induced in 4 search wires, at  $30^\circ$ , for a single-phase salient-pole alternator on short-circuit; static E.M.F. assumed sinusoidal, secondary actions neglected.

of the field due to the armature magnetomotive force. As a result the wave-shape of the static electromotive force induced in the various armature conductors will be somewhat different from those obtaining under similar conditions with cylindrical-field machines. A sinusoidal armature current will no longer give rise to a sinusoidal static electromotive force, and in addition the wave-shape will not be the same for all the conductors, but will depend entirely upon the position of the conductor.

For simplicity, however, it will be best to assume that the wave-shape of the static electromotive force due to the sole action of the armature currents is sinusoidal. As with the cylindrical rotor, the amplitude of the sine wave will depend upon the maximum value of the flux embraced by the coil under consideration.

Proceeding as with the case of cylindrical rotors, the resulting electromotive forces set up in four search wires equally spaced at  $30^\circ$  will be of the forms shown in Fig. 22.

To obtain the actual wave-shape of the static electromotive force induced in any particular conductor it is necessary to determine the manner in which the flux embraced by the coil of which the conductor forms part changes (the coil may be either ring or drum wound). For



FIG. 23.—Actual flux variations for coils embracing  $180^\circ$ ,  $140^\circ$ , and  $100^\circ$  respectively; due to the sole action of the armature M.M.F.; effect of pole fringe neglected.

the conditions at present assumed, viz. that the effects of the secondary actions are negligible, no particular difficulty attaches to this determination, but the method is tedious and nothing is to be gained by elaborating it here. The case of a single-phase machine with a pole-arc of two-thirds of the pole-pitch, i.e.  $\beta = 30^\circ$ , and with a two-thirds stator winding, has been worked out. The results are given in Fig. 23, which shows the manner in which the flux embraced by the various coils changes, the search conductors

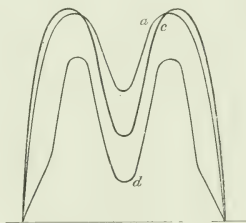


FIG. 24.—Static E.M.F.'s corresponding to the flux variations shown in Fig. 23.

being equally spaced at  $30^\circ$  and the pole fringe being neglected. The corresponding static electromotive forces are due to the rate of change of the flux, and are of the forms shown in Fig. 24. If the effect of the pole fringe is included, the wave-form of the electromotive force will much more closely approach a sine form.

An important difference from the case of the ideal polyphase machine is to be noted (Figs. 2 and 22). For the polyphase machine no electromotive force at all—neglecting the effect of the pole fringe—is induced in a conductor when it is not under the pole; for the single-phase machine the alternating armature magnetomotive force gives rise to an electromotive force of appreciable

magnitude when the conductor is in the interpolar region. As a result the polar portion of the E.M.F. wave is less clearly defined in single than in polyphase machines.

The resulting E.M.F. and current waves will still more largely depend upon the ratio of the pole-arc to the pole-pitch, and, independent of secondary effects, harmonics of the third and higher orders are to be expected for all cases.

#### SECONDARY EFFECTS.

It has already been stated and is well known that, as a result of the alternating armature magnetomotive force, induced electromotive forces and currents of double-frequency are set up in the pole-shoes, the poles, and the main exciting winding, and that these currents give rise to a magnetomotive force tending to limit the pulsations of the armature flux. With perfect damping, due to amortisseurs, the exciting winding would be screened from any changes of flux, and the conditions there obtaining would not differ largely from those which hold for polyphase machines. With normal single-phase machines amortisseurs are generally provided, but perfect damping is only possible with distributed amortisseurs, such as are formed by a squirrel-cage winding. In general, then, double-frequency currents are to be expected in the exciting windings. These currents react on the armature windings and give rise to an electromotive force of triple frequency and independent of the spread of the stator winding. As a result a third harmonic is to be expected in the current wave of single-phase machines on short-circuit, its magnitude, however, depending largely upon the extent of the damping action set up by the amortisseurs. The third harmonic in the current is to be expected further to give rise to an electromotive force of quadruple frequency in the exciting winding, which, in turn, will give rise to a fifth harmonic in the armature current, and so on.

#### EXPERIMENTAL RESULTS—SINGLE-PHASE MACHINES.

The oscillograms here given were taken on ordinary polyphase alternators working single phase. For the salient-pole machines no special damping coils were provided, and solid poles with laminated shoes were used. For the machines with cylindrical-field systems a squirrel-cage damping device was formed of the metallic slot wedges and the end covers of the rotor winding. The machines in every case date back at least six years.

The test results include machines of both types of field construction with one-third and two-thirds stator windings, obtained from ordinary 3-phase star-connected alternators, and a salient-pole machine with a one-half and a full-pitch winding, obtained from a 2-phase alternator.

The records taken on each machine corresponded to those performed on the 3-phase machines, and in every case the excitation was adjusted so that the active conductors of the stator winding carried their normal full-load current.

#### REMARKS ON THE EXPERIMENTAL RESULTS.

##### (a) SALIENT-POLE MACHINES. (FIG. 25.)

(1) *Electromotive force induced in the search coil.*—For reasons already given, no note was made of the position of the search wire, so that the wave-shapes of the electromotive forces induced in the various cases show consider-

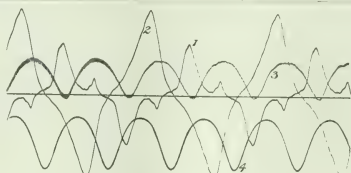


FIG. 25a.—Machine A.  $s = 2Q/3$ .

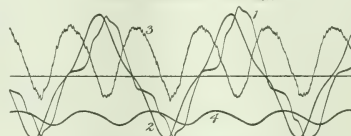


FIG. 25b.—Machine B.  $s = Q/3$ .

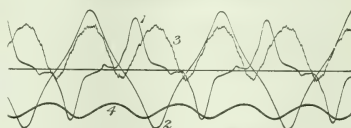


FIG. 25c.—Machine B.  $s = 2Q/3$ .

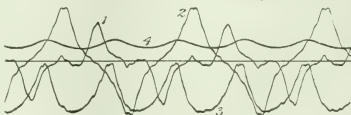


FIG. 25d.—Machine C.  $s = 2Q/3$ .

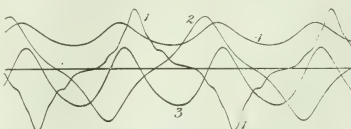


FIG. 25e.—Machine D.  $s = Q/2$ .

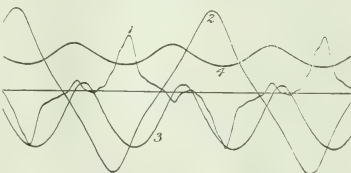


FIG. 25f.—Machine D.  $s = Q$ .

Figs. 25a–25f.—Short-circuit waves on single-phase salient-pole alternators. Machines are normal polyphase machines and have no damping windings.

able variation. It will be noted, however, that the waves correspond very closely to the forms predicted.

(2) *Armature current.*—In every case the current curve contains a fairly prominent third harmonic, varying in amplitude from 16 to 35 per cent of that of the fundamental. This represents a third harmonic in the total resulting E.M.F. wave of from about 50 to 100 per cent of the amplitude of the fundamental harmonic in the electromotive force. The magnitude of the third is influenced to a certain extent by the spread of the stator winding. Thus for machine D the current with  $s = \frac{1}{2}Q$  has a third harmonic of 22·5 per cent, whereas with  $s = Q$  the third is only 16 per cent of the fundamental. There are two possible reasons for this reduction in the third harmonic with the increased spread of the winding. The first is to be found in the reduction in the winding factor, which will cause the third harmonic in the dynamic component of the electromotive force to be reduced; the second is that the effect of the pulsating armature magnetomotive force is relatively smaller for the winding of large than for that of small spread. The large reduction obtaining for machine D indicates that the latter is the determining factor.

It will further be noted that wherever the pulsations in the magnetizing current are large, the third harmonic in the armature current is large, and vice versa. It is a matter of interest that the cases given in which the third harmonic in the current wave is most pronounced are both for machines having a two-thirds stator winding. Moreover, in these machines the fifth harmonic is of appreciable magnitude in the current wave, being set up by a current of quadruple frequency in the exciting winding. Still higher harmonics due to further such actions are distinctly observable.

The harmonic analysis of the various current waves is given below. Harmonics less than 5 per cent of the fundamental are neglected. Except in the case of machine A the curves are practically symmetrical about the 90° axis; the analysis given is therefore that of the equivalent symmetrical wave, except in case A. It must be remembered that errors in obtaining current waves are apt to occur, but there is no reason for doubting that the curve for machine A is correct, since the curve obtained for the 3-phase test on this machine—with the same essential connections—was quite satisfactory. Machine C gives traces of a somewhat similar effect.

- (1) *Machine A.*  $s = 2Q/3$ .  
 $i = 100 \sin \theta - 34\frac{1}{2} \sin 3(\theta - 13^\circ) - 9 \sin 5(\theta - 17^\circ) + 18\frac{1}{2} \sin 7(\theta + 12^\circ)$ .
- (2) *Machine B.*  
 (a)  $s = Q/3$ .  
 $i = 100 \sin \theta - 19\frac{1}{2} \sin 3\theta$ .  
 (b)  $s = 2Q/3$ .  
 $i = 100 \sin \theta - 17 \sin 3\theta$ .
- (3) *Machine C.*  $s = 2Q/3$ .  
 $i = 100 \sin \theta - 32 \sin 3\theta + 9\frac{1}{2} \sin 5\theta + 8 \sin 7\theta$ .
- (4) *Machine D.*  
 (a)  $s = Q/2$ .  
 $i = 100 \sin \theta - 22\frac{1}{2} \sin 3\theta$ .  
 (b)  $s = Q$ .  
 $i = 100 \sin \theta - 16 \sin 3\theta$ .

(3) *Potential difference between the excitation slip-rings.*—The alternating electromotive force of double frequency due to the pulsating armature reaction is in every case very marked. The effect of the spread of the stator winding upon the magnitude of this electromotive force is quite apparent; the smaller the spread, the greater is the relative effect of the armature currents.\*

This double-frequency electromotive force is in no case a pure sine curve, but contains a more or less marked second harmonic, that is, of four times the main frequency, due to the reaction of the third harmonic in the armature-current wave. The larger the value of this third harmonic in the current, the greater is that of the electromotive force of quadruple frequency induced in the exciting winding. In addition there is distinct evidence in the case of machines A and C of an electromotive force of six times the main frequency, set up by the fifth harmonic in the armature current.

In many cases the effect of the pulsating armature magnetomotive force is so marked as to cause an actual reversal of the potential difference between the rings for an appreciable interval of time, twice during every complete period. It is to be noted, however, that the magnitude of the third harmonic set up in the armature current is not solely influenced by the extent of the pulsations in the excitation voltage. As a matter of fact, of the cases given, the effect on the armature winding happens to be greatest for the machines in which the pulsations in the excitation voltage are smallest. The factor which directly determines the magnitude of the reaction set up in the armature winding is the extent of the variations in the exciting current.

(4) *Exciting current.*—Owing to the inductance of field windings, the pulsations in the exciting current are considerably less than those in the exciting pressure. The greater the electric time constant of the exciting circuit, the greater will be the reduction in the amplitude of the pulsations in the current. For machines A and C the time constant was relatively small, so that the current ripples are very pronounced, for the other machines the current ripples are considerably less, in spite of the larger fluctuations set up in the exciting pressure. Not only does the inductance reduce the magnitude of the fluctuations in the exciting current, but it also alters their wave-shape. This is due to the reactance of the winding increasing directly with the frequency, so that the higher harmonics are proportionally reduced. As a result the wave-shape of the ripples in the exciting current does not differ largely from the sinusoidal. In most cases, however, the presence of a ripple of four times the main frequency is distinctly discernible. In addition, the reactance causes a shifting of the phases of the various harmonics in the exciting current relative to those in the exciting pressure, and the flat-topped ripple in the exciting pressure gives rise to the pointed-topped ripple in the exciting current.

#### (b) CYLINDRICAL ROTORS. (FIG. 26.)

(1) *Electromotive force induced in the search coil.*—Again, owing to the varying positions of the search coil, the results for the cases given show considerable variation. The presence of serrated ripples due to the spacing of the excit-

\* Cf. the curves for machine B with  $s = Q/3$ , and  $s = 2Q/3$ ; and machine D with  $s = Q/2$ , and  $s = Q$ .

ing winding is again marked, as in the case of the 3-phase machines. With machine E it is apparent that the search conductor was towards the outside of the armature coil, *i.e.* as at *a* (Fig. 18), since the main and armature magnetomotive forces are practically in dead opposition, and the wave-shape is similar to that obtained with 3-phase machines. With machine F (Fig. 26c), on the other hand, the search wire must have been at the centre of an armature coil, as the effect of the armature magnetomotive force is almost nil, the E.M.F. wave being a slightly

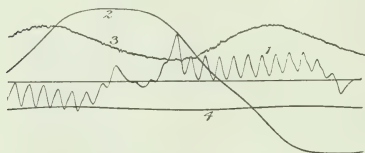


FIG. 26a.—Machine E.  $s = Q/3$ .

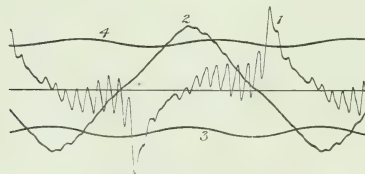


FIG. 26b.—Machine F.  $s = 2Q/3$ .



FIG. 26c.—Machine F.  $s = Q/3$ .

FIGS. 26a, 26b, 26c.—Short-circuit waves on single-phase alternators with cylindrical rotors. Machines are normal poly-phase alternators, but have dampers.

distorted version of that obtaining on open circuit. For the remaining case the search wire was obviously in an intermediate position.

(2) *Armature current.*—The deviation from a pure sine wave is very small, as shown by the analysis. Owing to the effective damping coils, the third harmonic is practically non-existent except in one case, the chief<sup>6</sup> of the higher harmonics being the fifth, and that is relatively very small and of no practical importance.

The amplitude of the wave being small, and the base large, the departure from the pure sine wave tends to appear greater than is actually the case.

The analyses are :—

(1) *Machine E.*  $s = Q/3$ .

$$i_1 = 100 \sin \theta - 3.5 \sin 5\theta.$$

(2) *Machine F.*

(a)  $s = Q/3$ .

$$i_1 = 100 \sin \theta - 6 \sin 5\theta.$$

(b)  $s = 2Q/3$ .

$$i_1 = 100 \sin \theta - 9 \sin 3\theta - 4 \sin 5\theta - 4.5 \sin 7\theta.$$

It will be noted that the fluctuations in the exciting current are only marked in the case of the machine for which the third harmonic is apparent in the armature current.

(3) and (4) *Exciting pressure and current.*—For machine E, which is of early date, a considerable electromotive force of double frequency is apparent in the exciting circuit. The reactance of the exciting circuit, however, was relatively so great that the fluctuations in the exciting current are hardly apparent. With the other cases the damping coils are very effective, and the fluctuations in the exciting pressure are very small; the variations in the exciting current are now trivial, although the reactance of the rotor circuit of the machines is not so large in proportion as that of machine E.

The tests on these machines emphasizes in a remarkable manner the very great benefits obtained by the use of squirrel-cage amortisseur coils.

## TWO-PHASE MACHINES.

With 2-phase alternators the rotating armature magnetomotive force is subject to considerable variations. Fig. 27

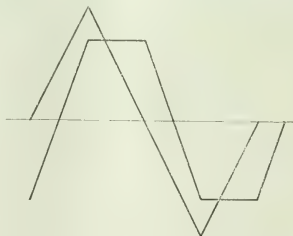


FIG. 27.—Limiting M.M.F. curves for 2-phase armature.

gives the limiting values of the M.M.F. curves that would obtain for sinusoidal armature current. The limiting values occur when the current in one phase is zero, and when the currents in the two phases are equal respectively. The frequency of the variations is thus four times the main frequency. As a result of these variations eddy currents will be set up in the pole-shoes, etc., which will tend to limit the changes in the value of the flux. Neglecting the effect of these eddy currents the limiting forms of the flux-distribution curve for salient-pole machines will be of the types shown in Fig. 28.

The pulsations in the value of the flux may also give rise to induced electromotive forces and currents of quadruple frequency in the exciting circuit. In turn these fluctuations

in the exciting current may give rise to electromotive forces in the armature conductors of  $(4 \pm 1)$  times the main frequency.

The pulsations in the armature magnetomotive force are much greater than with 3-phase machines, so that the case of the 2-phase machine differs from that of the ideal



FIG. 28.—Limiting flux-distribution curves for a 2-phase alternator on short-circuit; secondary actions and pole fringe neglected.

polyphase alternator to a much greater extent than that of the 3-phase machine. The secondary effects are in general appreciable, and the variations in the armature magnetomotive force cause E.M.F. ripples of appreciable magnitude to be set up in the induced electromotive force, even when the conductor is in the interpolar region.

#### EXPERIMENTAL RESULTS—TWO-PHASE MACHINES.

(FIG. 29.)

The only machine tested was a salient-pole alternator.

(1) *Electromotive force induced in the search coil.*—Except for the pronounced effect of the pulsating armature magnetomotive force, the wave-shape of the induced electromotive force does not differ from that obtained with the 3-phase machines. At the same time the fifth and seventh harmonics are far more pronounced than with the 3-phase machines, their origin being due to the reasons already given.

The analysis is—

$$e = 100 \sin \theta + 117 \sin 3(\theta - 24^\circ 5') \\ - 94 \sin 5(\theta - 25^\circ) - 95 \sin 7(\theta - 9^\circ).$$

(2) *Armature current.*—As expected, the wave contains both third and fifth harmonics, its analysis being—

$$i = 100 \sin \theta - 8 \sin 3\theta + 3 \sin 5\theta.$$

(3) *Exciting pressure.*—The pulsations of four times the main frequency are very apparent, their wave-shape being practically sinusoidal, and of an amplitude of 22 per cent of the mean value of the pressure.

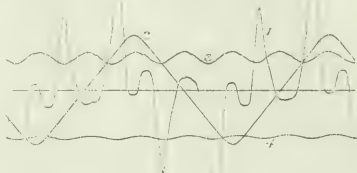


FIG. 29.—Short-circuit test on 2-phase alternator. Machine D.

(4) *Exciting current.*—The ripples in the exciting current are quite marked, but the inductance of the winding again reduces their amplitude relatively to that of the fluctuations in the pressure.

#### CONCLUSION.

The detailed study of the action of alternators working under steady short-circuit conditions serves also as an excellent example of the properties of non-sinusoidal electromotive forces. The difference between the wave-shape of the current and that of the electromotive force to which it is due is well illustrated. In addition the remarkable elimination of the higher harmonics caused by the spread of the armature winding in the case of 3-phase machines, in particular those with cylindrical rotors, is worthy of comment. Perhaps, however, the most outstanding feature is the presence of marked third harmonics in the current wave of single-phase machines having a two-thirds winding.

The author would like to take this further opportunity of expressing his indebtedness to Mr. W. Marden for the help he has given, and for his courtesy in permitting the publication of the various oscillograph records given in the paper.

## NEWCASTLE LOCAL SECTION: CHAIRMAN'S ADDRESS.

By P. V. HUNTER, Member.

(Address delivered 8 November, 1915.)

It is the *métier* of each branch of engineering to develop from a problem in science into a commercial business. Its votaries in the beginning are men of genius, and, at the end, of perspicacity. Engineers are expected to be both, as they belong to the intermediate stages of development.

In the successive stages of progress of such a branch of engineering as the production and supply of electricity, each new technical advance is examined with increasing severity to ascertain its financial advantages. As engineers in general devote a considerable period to the acquisition of the technical knowledge necessary for their work, they may be pardoned if at times they are a little restive at this commercial attitude towards their ideas. In any case there is generally among engineers a feeling of sympathy

large extent mean achieving the same thing at less capital cost. Electrical engineers have therefore to endeavour to cultivate a pleasurable feeling of satisfaction in achieving such results.

This attitude was necessary in ordinary circumstances, but under the financial conditions which must exist for some time as a result of the present war it will become of increasing importance. It is, I think, very desirable that engineers should appreciate these conditions, as disappointment and waste of time and energy may be thereby avoided.

It may be said with a remarkable degree of accuracy that we progress in proportion to our opportunities of correcting previous mistakes. This is true if we include

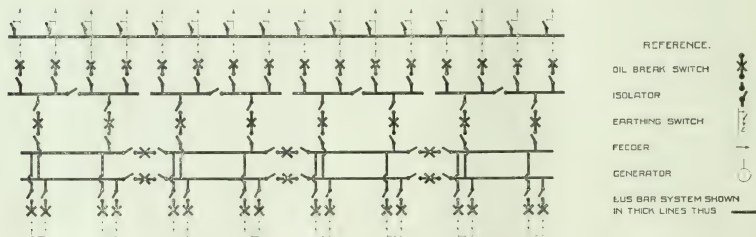


FIG. 1.

for one of their number who adopts something new without undue respect for its financial aspect. Only too frequently the more interesting engineering projects are among the uncommercial ones, at any rate at their inception. Unfortunately, electricity-supply undertakings in general present a very different financial problem from that of manufacturing concerns. The ratio of annual revenue to capital is low, as is generally the case in public utility undertakings. Quite commonly the annual income does not exceed 15 per cent of the total capital expenditure. Even this ratio is high, compared with railways where 10 per cent is a good figure and 15 per cent exceptional.

In the case of the electricity-supply undertakings the capital is turned over once in seven years and a 5 per cent annual return on capital necessitates that 35 per cent of the revenue shall be profit. In these circumstances where capital charges are so large an item, progress must to a

as part of the meaning of the term progress, commercial advantage. If progress is dependent on opportunities for repetition, it may be reasonably expected that certain elements of electricity-supply undertakings will have made greater progress than others. For instance, turbo-generators are more frequently constructed than generating stations, and for this reason their design more nearly approaches ultimate development. In the same way transmission systems have not reached the same advanced stage as cables, and switchgear apparatus is better designed than switchboards.

There are probably few engineers of experience who will disagree with these general statements of relative progress. A rough-and-ready test is that where the design is further advanced there is closer agreement among different engineers as to what is the best practice. Ultimately a stage is reached where there is sufficient agreement for a standard specification to be issued, and

further progress as a matter of engineering design largely ceases and the apparatus becomes a standard article of commerce.

Fortunately for those engineers whose interest is excited more by technical than financial matters, electric power supply still presents for solution some problems in which the technical requirements have not been completely

In Figs. 1 to 5 inclusive, I have shown in single-line diagrams the busbar connections of five important power stations in this country and America. The number could be considerably extended without repetition. These five have been chosen as they are all important stations where the final arrangement would be adopted only after careful thought and consideration. The difference between these

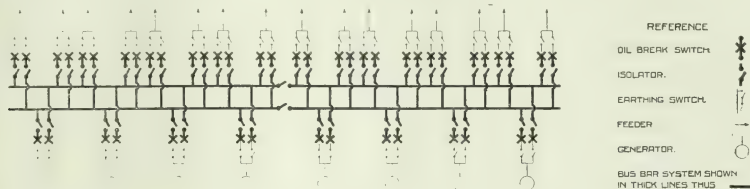


FIG. 2.

satisfied. In particular the diversity of opinion as to the correct design and arrangement of power-station switchboards\* is most striking. No two opinions appear to agree on the matter, and general difference will be found on such primary considerations as the proper number of busbars to employ. Switchboards appear in fact to have a stimulating effect on most engineers. Even the most

arrangements is striking, and the reason for it and advantages of one over the other not self-evident. All the arrangements have no doubt been influenced by experience with earlier switchboards which have given more or less trouble and led to more or less complication. An important object of the designer in each case appears to have been to provide for the immediate resumption of

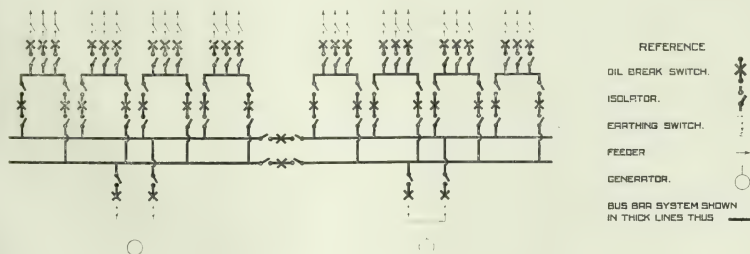


FIG. 3.

unimaginative appear to develop remarkable ingenuity when the problem is to evolve the perfect switchboard. This is no doubt largely due to the fact that a number of alternative arrangements readily present themselves, and there is in general little reason why one should be preferred to another. In any case that has been my own experience.

It is common to find two power stations of similar date in close agreement as to general design and lay-out but differing radically in the arrangement of the switchgear.

\* The term switchboard is a survival, and is in fact a misnomer when applied to modern switchgear which requires a large building full of masonry for its accommodation. The word is here used for lack of a better

supply under circumstances of failure of part of the switchgear itself. In fact the fundamental difference between the various arrangements is the degree to which they provide for internal breakdown of the switchboard. The more complicated arrangements make the more complete provision. In some of the arrangements as much as half of the equipment is provided for the sole purpose of dealing with internal failure. Whatever may have been the original object of switchboards when they were first used, the primary function of power-station switchboards such as those included in the diagrams is the maintenance of a continuous supply of energy independent of failure of any single part of the generating and transmission equip-

ment. In other words, switchgear is intended to give individuality to the various sections of a supply system, and for this purpose is made to operate automatically to cut off faulty sections.

If we have in a transmission system a cable with a switch at each end of it the combination of cable and switches is an independent section of the supply system with an identity of its own. If now we tee a branch cable on and provide it with a switch at the end remote

system into sections they each provide more or less against the effect of internal breakdown of the switchboard.

On the whole, such differences as are shown in Figs. 1 to 5 may reasonably be expected, since we are now dealing with something quite outside calculation, namely, the probability of an accident to or failure of any part of a switchboard. Few designers can be expected to have sufficient faith in their apparatus to base the arrangement of busbars on the assumption that a failure of any part will never occur. On

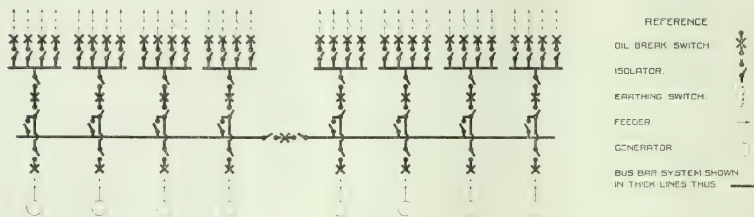


FIG. 4.

from the tee, we have merely increased the equipment comprised in the section, but we have not increased the number of sections. If, on the other hand, we install a switch on the added cable at the tee point, we now have two independent sections. Each generator or transformer with its own switch is, of course, also a section.

We may correctly define the primary function of switchgear as being to maintain supply by isolating faulty sections.

On the other hand there are equally few designers who do not recognize that the multiplication of parts in itself conduces to breakdown. The greater complication leads to mistakes by the operators, and the larger the number of parts the greater is the risk of failure. It is therefore a matter of some difficulty to settle with any degree of nicety the judicious mean between too much complication and too little security. It will, however, be of some help

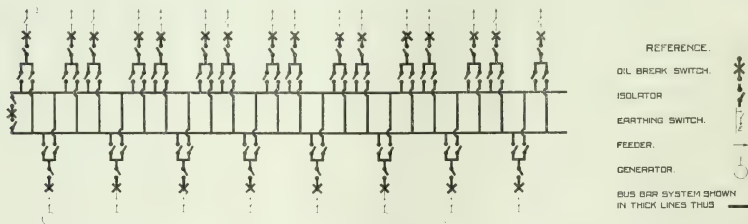


FIG. 5.

This function is performed by all the various schemes illustrated in Figs. 1 to 5. It is, however, logical to insist that before perfection is secured, switchgear should not only isolate faulty sections but should also provide against interruption of supply in the event of a breakdown of any part of the switchgear itself. This argument has the more force since failure of the busbars of a switchboard involves a number of sections.

It is in this respect that the various arrangements illustrated differ; that is to say, in addition to dividing the

and guidance if we approach the matter from the point of view of the two extremes and examine first what is the arrangement which makes no provision for a failure of the switchgear, and afterwards compare it with the other extreme where the arrangement is such that no single internal breakdown of the switchboard will affect more than one section. The simple arrangement is shown in Fig. 6; the other in Fig. 7. The busbars have been shown endless, as this gives complete symmetry, the least heating, and greatest economy in copper. The

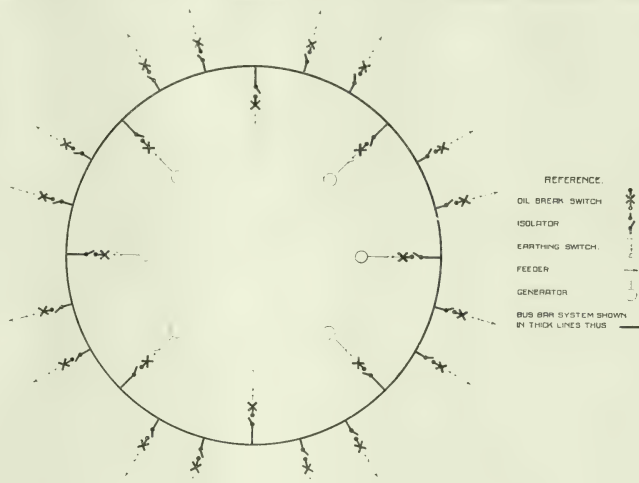


FIG. 6.

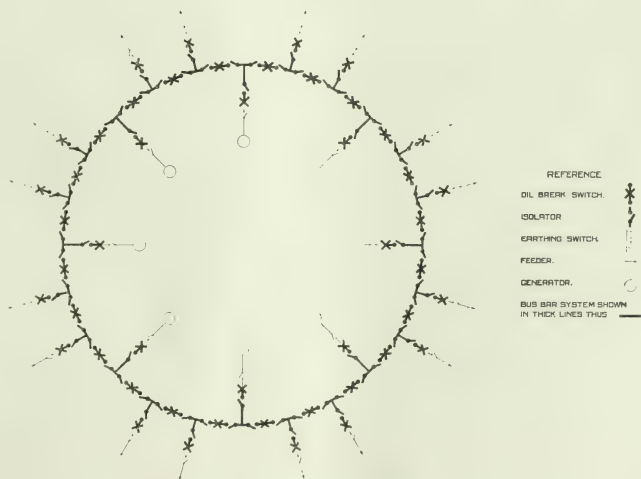


FIG. 7.

arrangement need not necessarily be circular in form, and it has been shown in this way for simplicity and convenience.

The various arrangements of busbars shown diagrammatically in Figs. 1 to 5 may each be regarded as some degree of compromise between Figs. 6 and 7, although in some of them the same result could have been obtained with less complication. The actual difference between Figs. 6 and 7 lies in the inclusion of busbar switches. It would seem quite reasonable that, if the effect of a busbar fault is to be limited, the proper way to do it is to divide up the busbars into a large number of separate parts, each part being so small that it includes one section of the system only, the working of the remainder being independent of it. The busbar switches shown in Fig. 7 are the result of this view. Fig. 7, although a logical arrangement, is

typical arrangement of the kind referred to. In this arrangement the busbars have been shown endless, but arranged in a rectangle. This is the equivalent of the circular arrangement shown in Figs. 6 and 7, but it is the more practical form. It requires a building which can be given some architectural proportions without difficulty. The arrangement shown in Fig. 8, it must be admitted, is not perfect. A busbar fault would put out of service a fairly large amount of plant. It does, however, give sufficient facilities for cleaning and maintenance in all ordinary conditions of switchboard service.

It is, I think, permissible to take the view that, in general, rather than resort to a more complicated arrangement than Fig. 8, the money would be better spent on apparatus having larger provision against accident or breakdown. In other words it would be better to prevent

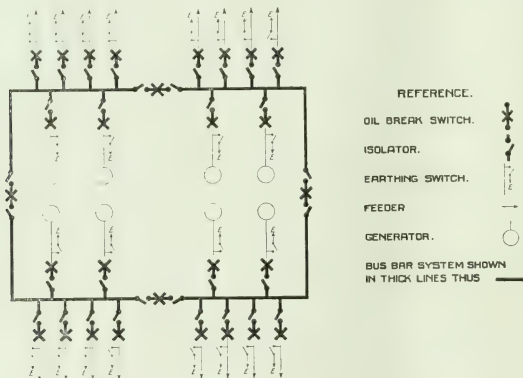


FIG. 8.

hardly a commercial one, however important may be the supply given from the busbars. The number of switches is double that included in Fig. 6, and it is difficult to justify such a large expenditure in order to provide against a contingency which experience shows may not occur once in 10 years with soundly constructed apparatus. On the other hand, Fig. 6 makes no provision even for overhauling or cleaning the busbars without a complete shut-down.

In general therefore some compromise between the two will meet with approval, as is evident from Figs. 1 to 5. To some extent the degree of complication necessary will depend on the character of the load. On certain loads little opportunity occurs for taking generators and feeders out of service, and in these circumstances busbar switches would have to be more frequent. It is a fairly safe rule not to include more than two generators on one division of busbar, and if the generators are exceptionally large it is better to reduce the number to one. Fig. 8 shows a

trouble than limit its consequences. This suggestion, of course, raises a somewhat large matter and one which can hardly be dealt with adequately in this address. I shall therefore touch only on one or two points of interest.

The first consideration is: What are the more common kinds of trouble met with in switchgear? According to my own experience, and arranged in order of frequency of occurrence, they are the following:—

- (1) Mistakes made by the operating staff;
- (2) Unforeseen effects;
- (3) Failure of apparatus due to weakness or deterioration.

I am not satisfied that the mistakes of the operators are due to any particular type or class of man. The more cautious men are on occasions found to offend. The most frequent mistake is to open the isolator of a feeder carrying load instead of the one next to it. Such an occurrence in a large power station involves substantial risk of permanent injury to the operator, if not actually to life. The penalty

for a mistake is therefore distinctly severe. Notwithstanding this risk these troubles do occasionally occur and are really due to the fact that a switchboard consists of a large number of similar parts of identical appearances, the only distinction being in the labelling. It is therefore a remarkably easy matter to mistake one panel for the next. Painting the names of the panels on them is not a sufficient safeguard, however prominent the lettering. Various proposals have been made from time to time, such as painting each panel a distinctive colour all over and using a sufficient number of different colours to avoid a repetition on two panels close to each other. Other ways of making each panel more or less distinctive from its neighbours will occur to any one. Notwithstanding this, the most satisfactory arrangement is a complete system of screens and interlocking. The arrangement can be made to provide that no access can be obtained to conductors while they are alive, on account of the screens being automatically locked under these conditions. The oil switch is interlocked with its isolators so that the latter cannot be opened or closed while the oil switch is closed. There still remains the difficulty that the feeder terminals may be alive through some mistake in not opening the switch at the other end of the feeder. This is met by replacing the disconnecting switches normally used between the switch and feeder by a set of earthing switches. This arrangement has been shown in Fig. 8.

Interlocking, if adopted at all, must be complete, as partial interlocking leads to more accidents than its complete absence. The whole of the safeguards described above can be met by a single locking bar if a simple arrangement of switchgear is adopted.

The busbars themselves have to be dealt with separately. A simple method is to treat each length of busbars between busbar switches as a unit and place it and the isolating switches disconnecting it from the oil switches in a gallery. Access to the busbars is obtained by means of a door at each end of the gallery only. A locking bar from end to end of the gallery is provided. This bar cannot be rotated into the position which allows the two doors to be opened until every oil switch connected to the particular length of busbar (including the busbar switches) is open and isolated.

These precautions, if carefully designed and constructed, are not expensive compared with the alternative of more complicated switchgear, and should give immunity from mistakes leading to breakdown on the switchboard itself. There still remain other possibilities of mistake, such as closing the switch of a standing generator or making alive an earthed feeder. These do not, however, properly come under the classification of accidents to the switchgear, although they are no less annoying on that account. They are classed as the breakdown of a section, and in each case the faulty section should be disconnected from the system by its oil switch.

Under the heading of unexpected effects the principal item is abnormal mechanical forces occurring on short-circuits. The most trouble has been experienced with isolating switches opening unexpectedly. These forces are now generally recognized and can be provided against.

Another possible source of trouble is the fusing of the primary windings of current transformers having wound primaries. These windings are often run at a fairly high

current density and the cross-section is proportioned to the full load of the circuit. The short-circuit current which each may have to carry in emergency for a short time is not dependent on the circuit, and there is distinct danger that if the section be less than a certain minimum, depending on the short-circuit current of the power station, the winding will be fused.

Current transformers are also subjected between turns to an abnormal peak voltage due to saturation in the iron circuit on the occurrence of these heavy loads. This is a particularly objectionable fault, as it may puncture the insulation between turns and alter the ratio of the current transformer while the short-circuit lasts. Afterwards the potential disappears and sometimes with it the breakdown between turns. If then tested the current transformer may give normal ratio for currents of the order of full load.

It is generally known that when opening heavy loads oil switches give off vapours and gases which are explosive when mixed with air. This has led to the strengthening of switch tanks. It is not so well known that these vapours and gases are highly conducting. I have, however, known of cases where oil switches have successfully opened heavy short-circuits and the gases afterwards escaping from the switch have produced another short-circuit outside the switch. I suspect that on occasions similar occurrences have been thought to be potential surges produced by the switch opening the circuit improperly. Proper ventilating ducts for the switches help to prevent this trouble, but it is also a desirable precaution to place each oil switch in a cubicle to itself and insulate all live copper in the cubicle.

Failure of switchboards through deterioration is of rare occurrence; experience has led to the use of materials of permanent character, and in particular rubber insulation for high-tension circuits has been abandoned. A more frequent occurrence is that the duty required of a switchboard may, with the growth of the generating system, in course of time exceed the rupturing capacity of the switches. This condition when it arrives is not always properly recognized and the resulting troubles have frequently induced an undue pessimism respecting the possibility on large systems of breaking heavy short-circuits by oil switches.

This impression has been assisted rather than dispelled by the use of reactances. These devices were originally introduced for the purpose of assisting existing switches to stand up to a duty which in course of time had been found to exceed their capacity on account of growth of the system. They have proved so useful that there is some danger of their retarding the progressive improvement of the oil switch. I cannot but feel that this would be most unfortunate. Much as I appreciate the assistance to be obtained from the use of reactances in severe conditions, I have great faith in the oil switch and the possibility of developing it to meet all requirements. The ability of an oil switch to rupture circuits transmitting hundreds of thousands of kilowatts is one of the most remarkable phenomena in electrical engineering. It is at the same time one about which least is known and on which no research work worthy of the name has been carried out.

Opinions differ on the most elementary matters connected with its action. There is, for instance, no settled

opinion whether or not a number of arcs in series are more efficacious than one or two only. In the circumstances I feel strongly that every effort should be made to assist its development.

To return to the problem of switchgear arrangements, it is, I feel sure, better procedure to adopt arrangements preventing those particular faults to which switchgear is most liable, than to regard the faults as inevitable and provide complicated arrangements to limit the extent of them. In this connection there is little expense involved in making the insulation of switchgear the strongest part of the whole system, and as this ensures that whatever may break down due to abnormal potential the switchgear will be the most immune, it is a precaution well worth adopting. In my opinion 20,000-volt insulation for 10,000-volt switchgear, and similarly for other pressures, is not an extravagance.

The extra cost, provided the switchgear is simple, is a small matter.

In conclusion I would say that experience leads me to the view that it would be a mistake to attempt to standardize switchboard arrangements or switches. The experience of switchboard troubles on which I have based the views expressed is, of course, limited and certainly not of the kind justifying any dogmatic attitude. The most, I think, we can do at the present is to endeavour to avoid spending money without real and proved necessity.

My personal opinion is that there is strong probability that future developments will include, not only safety interlocks, but the complete abandonment of bare conductors for high-tension power station switchboards, and that the security of supply obtained in this way will justify the use of a minimum of switchgear.

## YORKSHIRE LOCAL SECTION: CHAIRMAN'S ADDRESS.

By H. HODGSON WRIGHT, Member.

(Address delivered 11 November, 1915.)

Contrary to the optimistic opinions expressed in some quarters at the beginning of the war, the Allies are still fighting the common enemy, who began the war with a breach of a solemn covenant and is carrying it on by methods which he has bound himself to abjure and which are, apart from any covenant, manifest crimes against civilization, not warranted even by any military necessity. Much endurance, sacrifice of blood and money, national and personal, will still be required to carry the struggle to such a conclusion as shall prevent a recurrence a few years later.

The one outstanding fact that this world war has taught us, is that success cannot be won without the aid of the engineer and mechanic, and an organized production of munitions of war on a scale far vaster than ever imagined before. In no previous war has the engineer, both mechanical and electrical, played such an important part. The rapid production of guns, rifles, shells, bombs, not to mention wireless apparatus, telephones, and the thousand-and-one other pieces of complicated apparatus necessary for the equipment of our navy and army, has resulted in a state of activity in our workshops and arsenals never before approached.

New methods of attack have necessitated new means of defence and new weapons, and scientists and engineers have been called upon to solve the new problems involved. The highest and most specialized skill of our engineers, metallurgists, and chemists is directly pitted against the skill of the enemy in the production of new designs, new metals, and explosives. Every new weapon must be an improvement on the last; thus the war is proving a great spur to invention in every branch of engineering.

Science has been organized; its units have been registered, and the best brains of the professors and

students of science throughout the Empire are being made use of. Thus our universities are devoting a large part of their attention to national needs. Scientific advisory committees have been formed to meet manufacturers and lay before them the results of their researches. We may congratulate ourselves as a Local Section that, in this manner, since the beginning of the war the research work in the production and improvement of steel carried out by the University of Sheffield has been of the greatest value to the industries of that district. The quality of the steel for munitions is the most important of the material factors which will decide the issues of the war, and it is satisfactory to reflect that this Empire has a far larger capacity if properly organized, and a better equipment for the execution of this task, than Germany and Austria.

Twelve months having passed since the Address of our immediate Past-Chairman,\* I propose to devote a few remarks retrospective to some of the points raised on that occasion. They have an even greater significance to-day, in the light of the present situation.

The address very properly indicated the duties devolving upon those of our profession remaining in civil life. I only propose to refer to three of these duties, which are interdependent and inseparable.

The first is: To do all possible "to support the sentiment 'Business as usual' with regard to the electrical industry in particular and to all other British industries in general." Whilst this sentiment was at that time admirable in itself, to indicate that our factories must be kept going, it must not have the effect of weakening our determination to put the last ounce of energy into the production of munitions. At the present time, therefore, the sentiment "Nothing as usual" would be more appropriate. Twelve

\* *Journal I.E.E.*, vol. 55, p. 33, 1915.

months ago only our largest engineering works were organized for the production of munitions. Now nearly all, irrespective of size, are "controlled" by the Government.

Secondly, "To assist in every way possible the efforts which are being made by British manufacturers to capture and retain such foreign and colonial trade as has hitherto been in the hands of the enemies of this country."

During the war we have an industrial breathing-time so far as German and Austrian competition is concerned. What measures are we taking as an electrical manufacturing industry, either individually or collectively, to conduct the coming industrial war? Once hostilities are ended, the ability and organization of Germany will be directed to underselling us in every market of the world. Prohibitive tariffs will to a large extent prevent her trading with Belgium, France, Italy, and Russia for many years. Whether we shall allow her to compete freely with us and our allies within the Empire is, I hope, at least doubtful. A much restricted world market is for her, in any case, certain. Nor shall we ourselves be free from severe competition by our allies and by neutrals, particularly America. In Germany economic causes will force a reduction of wages, and a flood of cheap German goods will result. No great wage reductions are probable in this country.

To meet these conditions we must cheapen production by better organization, and by improved machinery, designs, and co-operative sale methods. Increased efficiency of production and the utilization of existing and new scientific methods are absolutely necessary if we are to hold our ground against the coming competition. We need a higher and more general standard of specialized technical education for our engineers.

It is here that Germany has gone ahead since 1870. She was the first country to bring a scientific and methodical spirit to bear on the organization of technical and commercial education, her first technical school being founded in 1745. She has thus reaped the benefits of that education in the organization of her factories.

Many manufacturers still continue the old-fashioned sale methods of waiting for customers instead of waiting on them. There must be a complete change of these methods. A much closer study of foreign markets is needed; for that purpose a thorough technical and commercial education is as necessary for our salesmen as for our engineers. Much foreign business has gone to our competitors owing to our neglect and lack of commercial organization in foreign markets. Our expert salesmen should have passed through every shop and should have held positions in the estimating and designing departments, and should be capable of advising customers on highly technical questions. If financial reasons prevent the employment of a staff of highly salaried commercial experts abroad, then costs may be reduced by co-operative sale methods.

By carrying the same principle a step further, electrical manufacturers would extend their foreign markets by combining to charter an electrical exhibition ship fitted up with those goods which are most in demand. The cost per firm need not be much more than that of a land exhibition. The ship might be chartered every four or five years, and the stay at each port would be determined by the importance of the market. I am confident that

a co-operative scheme of this kind is possible, and would result in the capture and retention of much valuable trade formerly held by enemy competitors.

Far too little attention has been given by our sales engineers to the study of foreign languages, and I strongly recommend our junior members, whose duties may take them to foreign countries in later years, to learn at least one language besides their own. Yet it appears to me that, however perfect we may be individually as salesmen, and however closely we may study foreign markets, there will still be wanting for complete success that organized State assistance which Germany has so lavishly extended to her foreign industry.

Our foreign trade can never be fully developed without diplomatic, legislative, and financial assistance. The Board of Trade, as at present constituted, and the diplomatic and consular services, as carried on by the Foreign Office, are not adequately equipped for the encouragement and protection of our foreign trade. The Board of Trade was originally intended to deal primarily with transport, *i.e.* shipping, railways, and carrying agencies. The great spending departments of the Government are controlled by the Admiralty and War Office. Is it not quite as important that the earning or trading side should be also controlled by a separate Government Department?

A permanent and non-party Board of Industry is required, presided over by one of our most experienced business men and advised by a permanent staff of experts.

It is almost incredible that practically no funds are set aside by the State for the purpose of advancing foreign trade. In the year 1913-14 the amount of our foreign trade was over 1,400 millions, yet the cost of running the whole of the Board of Trade, including the Home Departments, was only £213,000. Apart from the Consular services, the Foreign Office staff interested in trade in foreign countries usually consists of commercial attachés, having little or no special knowledge or commercial training, and who use their office as a step to advancement. But the limited number of these officials renders their work of small value. China, with a population of 400 millions and yearly import trade of 80 million pounds, has one commercial attaché.

It would be the business of the Board of Industry to appoint qualified trade commissioners in our Colonies, dependencies, and all foreign countries, whose function would be:—

To collect and report to headquarters all useful information as to trade openings and the activities of our competitors;

To negotiate for improved and if possible preferential trade relations, notably in connection with international loans;

To counteract and prevent the dissemination of false and injurious political and commercial information by enemy competitors.

The third duty is "To consider carefully the methods of educating and training young electrical engineers with a view to reorganizing and improving such methods, so that in future the design and manufacture of all electrical apparatus required for the Naval and Military Services shall be carried out by British-born subjects. Special attention should also be given to business training, so that the methods of British firms may be entirely up-to-date and

their sales organization controlled by our own countrymen."

The importance of the proper scientific training of our electrical engineers, and indeed the complete overhauling of our present education system, is a subject of special interest to me, and one which is vital to the electrical industry.

It is a remarkable fact that England, the birthplace of modern industry, is the last of the great nations to build up its educational system. The close of the 18th century saw public provision made for schools in Württemberg, Saxony, and Prussia; and the opening of the 19th century witnessed the creation of a complete system of education of all grades in France under the direction of Napoleon. It was not until 1870, however, that our parliament established national elementary schools, ensuring primary education for all; and we are still to-day behind other great nations in making public provisions for the higher branches of education.

It would be out of place here to examine the causes of this apparent lack of initiative on our part. It may be said, however, that in the case of France and Germany external political forces, coupled with the need of unity for defence, have brought about the consolidation of their education systems. With us the force was an internal one, namely the establishment of democracy, which demanded a certain minimum of enlightenment on the part of those who have a share in the Government. Even at the present day we have no national system other than that of elementary education, which is very far from meeting the needs of the nation.

The inseparable relationship between education and national success in commerce and industry is a fact which hardly needs proof, but which will become more accentuated as years go on, owing to the higher standard of training required by our artisans and engineers.

One of the first duties of our legislators after the war should be to provide the country with an organized system of compulsory primary and secondary education forming a co-ordinated step to our technical high schools and universities.

The leaving age for primary schools should be raised, and attendance at the continuation schools made compulsory. The last period at the primary school should be devoted to a pre-apprenticeship training, during which the youth's aptitude, or otherwise, for engineering would be proved.

Our present haphazard apprenticeship system, or want of it, results in lads being put into trades for which they have no natural ability. The financial position of the parents only too frequently demands that the boy be put to the trade which pays the highest wages, irrespective of his aptitude for it. It should be the special duty of the teachers during the pre-apprenticeship period to note the boys likely to be suited to skilled handicrafts. The teachers should be encouraged to acquire a first-hand knowledge of the scope and requirements of the local engineering trades by study and by visiting the works. A much closer collaboration between the education authorities and the engineering employers is necessary and would lead to more suitable youths being selected for trade apprenticeship.

In 1905 the Leeds Education Authority started as an experiment a Day Preparatory Trades School for boys between 12 and 15 years of age. It has proved a decided

success. The same idea has been further developed by superimposing a similar practical course upon the education now given. It is thus gradually becoming recognized that the only effective way to train the rising generation of skilled workmen after leaving the elementary schools is to have half-time in the workshop and half-time in the technical school between the ages of 14 and 18.

A number of our principal technical schools give a two or three years' day course of instruction for student apprentices during the winter months. These are steps in the right direction and I should like to see the scope of the classes widened to form part, or an extension of, our elementary education system with the grant of a leaving certificate. This certificate would be a guarantee that the boy had attained a definite standard of education, and it would thus gradually become a qualification required by the engineering employers for trade apprentices.

Usually engineering works do not provide special facilities for practical training, and the apprentice has to pick up such experience as he can in a more or less haphazard fashion. In a few British and certain German and American works, however, special schools and training shops are provided; and one, at least, of our foremost electrical manufacturing concerns has an admirable apprentice school. The instruction is divided into two classes "General" and "Trade." The "General" class is a continuation of the apprentice's regular education, and affords proof that our elementary education system is not turning out boys sufficiently educated to make their way into skilled trades. The remedy for this is in the trade schools. The second or "Trade" class is devoted purely to trade teaching and consists of youths selected from the general class. The teaching of both classes is undertaken by the firm's engineering staff, assisted by leading foremen and shop engineers, and is carried out in working hours and at the firm's expense. The first object of the school is to turn out good workmen; its second to fit them for promotion to positions as charge hands, foremen, and inspectors. The quality of the workman is thus raised and with it the standard of the foremen.

Whilst it is both possible and profitable for a large firm to provide its own trade school, for small works it would be impossible for financial and economic reasons, except by a co-operative school system to which each firm would send its own teachers and pupils. Such a system would not be easy to carry out in practice owing to difficulties of distance, etc. It is to be hoped that ultimately the need for such schools will be met by the half-time trade classes provided by the Education Authorities in all large industrial centres. It must be noted that the improved educational facilities discussed will gradually result in increased numbers rising from the ranks of labour to fill the commissions of the engineering industry.

The foregoing remarks apply to those, the majority of whom are likely to remain workmen all their lives.

Turning to the consideration of the technical engineer, we may divide his specialized training into that of "Design," "Works Management," and "Commercial Engineering."

The education of our technical engineers is built up on the secondary or public schools forming an intermediate step to the higher technical school. It has been said that the

rapid commercial advance of Germany is due to her system of higher technical education. It would, however, be nearer the truth to say that it is due to a combination of causes, of which this is only one. Her system of highly efficient non-technical secondary schools has contributed quite as much to that advance, for without them higher technical education would have been impossible.

In this country we make the mistake of allowing technical instruction to be given too early, instead of postponing it till after the completion of a thorough secondary education. If it is desirable that our primary instruction should be a matter for public control and supervision, it is doubly the case with our secondary and higher instruction. So long as State control stops here and no contact and co-relation exists between our popular instruction and the instruction above it, so long will our education system be unsatisfactory. The primary school naturally presses up to the secondary sphere, and the secondary to the university or higher technical school. They should be inseparable and co-related, thus forming a highly efficient instrument for the avoidance of friction and competition.

Not only must the steps in the education ladder be inseparable, however, in the sense indicated, but there must be a closer association between our universities and technical high schools and the engineering industry. Much of their work is of a purely academic character and has little practical application.

I am convinced that great advantages would result to the electrical and engineering trades if they would submit to the universities for solution those problems which they have neither the staff nor the time to solve. Such a connection could not fail to be of great mutual value and

would result in manufacturers taking a keener interest in technical education and the teaching staff being in closer touch with industrial problems.

The loss of the colour industry to this country is an illustration of this lack of association. Professor W. H. Perkin, in his Presidential Address in March this year before the Chemical Society, showed clearly that this is directly owing to the neglect of organic chemistry by our universities in the past, and that even to-day it is not receiving in this country the attention due to such an important branch of science.

Immediately the war is over, Germany will endeavour at all costs to recapture her lost foreign trade, and we may be certain that she will flood the world with low-priced German goods. The strongest weapon we can forge to meet that competition is without doubt to look carefully to the better training of our artisans and engineers. The industrial race between nations will begin and the prize will be to the swift. Those who are least likely to prove swift are those whose fitness for the contest has been neglected by their countrymen.

The Institution is one of the channels through which we can make our influence felt on questions within its legitimate scope, and there can be no doubt that technical training is one of them. The subject is a well-worn one, but nevertheless it is one which I feel is of such extreme importance that nothing will be lost and much gained if the members of the Yorkshire Local Section will use their influence in the way suggested. By so doing they will be contributing to the object for which the Institution was founded, namely, "To promote the general advancement of electrical and telegraphic science and its applications."

## PROCEEDINGS OF THE INSTITUTION.

581ST ORDINARY MEETING, 18 NOVEMBER, 1915.

Sir JOHN SNELL, Past President, took the chair at 8 p.m. The Minutes of the Annual General Meeting held on 27 May, 1915, were taken as read, and were confirmed.

The CHAIRMAN: During the recess the Institution and the whole electrical industry have lost the services of a very valuable and useful member, the late Mr. Robert Hammond. Mr. Hammond, as so many of us know, rendered yeoman services to the Institution. As the Honorary Treasurer he did, what perhaps only the Members of the Council know so well, very useful work for us; and it is a very great loss that he should have been taken. I ask you to pass in silence a vote of condolence with Mrs. Hammond and with his son, Captain Hammond, who is now at the Front.

The Resolution was carried in silence, all present standing.

The following donations were announced as having been received, and the thanks of the meeting were accorded to the donors:—

*Benevolent Fund:* P. F. Allan, J. Ardron, F. C. E. Burnett, J. D. Dallas, The Diesel Engine Users' Association, A. R. Everest, M. Farrer, The Institution of Railway Signal Engineers, R. J. Kaula, W. E. Lane, Professor T. Mather, F.R.S., A. J. Newman, F.C. Raphael, S. Sharp, S. Simpson, R. T. Smith, A. Williamson, and The "25 Club."

*Building Fund:* G. M. Robertson.

*Library:* T. C. Baillie, D.Sc., C. Ashmore Baker, K. Birckeland, W. C. Clinton, E. H. Crapper, P. R. Friedlander, V. A. Fynn, E. Garcke, P. J. Haler, K. Hedges, Professor A. E. Kennelly, D.Sc., G. D. Knox, P. Lobel, W. T. Maccall, W. P. Maycock, D. Murray, D. Owen, W. T. Taylor, W. N. Twelvetees, Professor Miles Walker, The Astronomer Royal, The Board of Education, The British Thomson-Houston Company, Ltd., The Cambridge University Press, Messrs. Chapman & Hall, Ltd., Messrs. Constable & Co., Ltd., The Dominion Water Power Branch (Canada), The Engineering Standards Committee, The Hydro-Electric Power Commission (Ontario), The Institution of Automobile Engineers, The Institution of Railway Signal Engineers, The National Electric Light Association, The Executors of the late Sir William Preece, Messrs. Ridsdale & Co., Ltd., and Messrs. E. & F. N. Spun, Ltd.

*Museum:* H.M. Queen Alexandra, C. W. Cooke, F. N. Haward, K. Hedges, E. M. Hughman, W. Kingsland, T. Blackwood Murray, Professor S. P. Thompson, D.Sc., F.R.S., J. Christie (on behalf of Brighton Corporation Electricity Works), The Corporation of Trinity House, F. Harman Lewis (on behalf of Leyton Urban District Council), and C. Rodgers (on behalf of Messrs. Siemens Brothers Dynamo Works, Ltd.).

The CHAIRMAN: I should like to make special mention of the gift which we have received from Her Majesty the Queen Mother, of which notice appeared in the Press during the recess. Suitable acknowledgments were sent to Her Majesty.

I have to announce that the Council have elected Mr. J. E. Kingsbury to be the Honorary Treasurer of the Institution in place of the late Mr. Robert Hammond. I am sure the Institution can congratulate itself upon having the services of so useful a Member as Mr. Kingsbury, who for so many years has taken such a keen interest in the work of the Finance Committee.

I also have to announce that the Council have elected as an Honorary Member of the Institution, Monsieur Maurice Leblanc, who was for many years Professor at the École Supérieure des Mines, retiring from that position in 1909. He was one of the founders of the Société Internationale des Electriciens, and was President of that Society in 1906. In conjunction with Hutin he introduced the damping device known as the amortisseur. He has been President of the International Electro-technical Commission since September 1913. I am sure the selection of the Council will meet with the approval of the Institution.

I now have to introduce to the Institution Mr. D. J. Blaikley, who is going to present to us a most valuable collection of papers of the immortal Michael Faraday.

Mr. D. J. BLAIKLEY: I feel very happy in having the opportunity of presenting in person to the Institution the collection of books and papers that are now on the table. Members may like to know in what way these came into my possession, and why I am authorized to act in the matter. Faraday, as many members will know, was born in 1791, and died at Hampton Court in 1867. For a long time during the later years of his life his niece, Miss Jane Barnard, lived with him and his wife as a daughter of the house. Miss Barnard died on the 26th July, 1911. I had a lifelong intimacy with her; her younger sister is my wife. In connection with her will, she left in my hands as a matter of trust these books and papers. She offered certain suggestions as to their disposal, but as a matter of fact left the final decision entirely in my hands. On looking over the papers, I found that Mr. Mordey had been in touch with Miss Barnard on the matter for a short time before her death, and from certain memoranda among the papers it appeared clear that, although it was not explicitly expressed in her will, she desired that Mr. Mordey should be consulted and have some voice in the matter of their disposal. The letter under which I act was written to me by Miss Barnard on the 28th November, 1904, seven years before her death; and the chief condition that I would wish to be observed in connection with the acceptance of the gift, is expressed in the following words, extracted from that letter:—

"That such documents should be available for any future biography or other work about Faraday."

With this in view I suggest:—

(1) That these papers might be made the subject of a special trust in a somewhat similar way to that in which I understand the Institution holds the electrical library of

Sir John Snell.

Sir John Snell.

Mr. Blaikley.

Sir John Snell.

Sir Francis Ronalds, so that in the event of the Institution ceasing to occupy the position it now occupies, the Faraday collection should not be considered as an asset of the Institution, but should pass to the British Museum.

(2) That the papers should be kept together and intact as a separate collection available at all reasonable times, not only to the members of the Institution, but to the public on suitable introduction.

(3) That if upon examination and classification the Council should decide that any of the papers are not of sufficient interest to warrant their preservation, such papers are not to be destroyed, but should be returned to me.

(4) That my son, Mr. Alec. J. Blaikley, of the Société Générale de Paris, and "Talsarnau," Nether-street, Finchley, who was one of the executors of Miss Barnard's will, should have, with a friend, a special right of access to the papers, and of acting for me under (3) if occasion arise.

I have a personal remembrance of Faraday. I need hardly say it will be no surprise to anyone who knew him personally or has read much of his life, that the remembrance is a very pleasant one. Many biographies have appeared, the most comprehensive being that by Dr. Bence Jones, "The Life and Letters of Faraday." Others, including Professor Silvanus Thompson, have written very interesting and brief biographies. My own remembrances go back to my early childhood. Quite apart from his power as an investigator and original thinker, colossal in his powers, there was a great deal that interested everyone with whom he came in contact. His sympathetic kindness, his keen sense of honour, and his hatred of anything like shams, whether scientific or of any other kind, were very noticeable. My first remembrance of his public work is this. I had an opportunity of being present as a child—I suppose I was then just about 11 or 12 years old—at a lecture on metals, one of the course of juvenile lectures for the season given at the Royal Institution. It was an occasion when the Prince Consort and his two sons, our late King Edward and the Duke of Edinburgh, were present. A little later I was again at the Royal Institution in Faraday's rooms on the occasion of a juvenile party, when, after various childish games and amusements, he took us all down to the lecture theatre, allowed us to play romps round the gallery, and then showed us a number of most interesting experiments. Towards the end of his life—about two years, I think, before his death—I was in his rooms again one evening at the Royal Institution when he was very much interested in some new piece of electrical apparatus which had just been brought to the Royal Institution for his inspection. I mention this as an instance of his keen sense of honour in what was due to others. With Miss Barnard he began experimenting with the machine. Something did not quite answer his expectations, and Miss Barnard said, "Oh, let us alter this or that; let us try this or that adjustment." If it had been a mere matter of adjustment no doubt he would have done it, but if it came to an alteration of some portion of the apparatus without the knowledge of the designer or owner he would have nothing to do with it. I remember perfectly well, even to this day, that his words were: "Jane, we have no right to touch it; it is not ours." My last sight of him was about four months before his death, the time being April 1867. At that time he had much failed, and his manner was that of second childhood. He was glad to be

wheeled in a chair along the corridor and through his suite of rooms, and he sat at the window in the evening, as the light was failing, merely interested in watching the people going into the evening service in the chapel or church opposite.

These books which I am handing over to the Institution comprise his common-place book, dated 1816–1846, filled up with many memoranda on all manner of subjects as they occurred to him as being worthy of record; a book of chemical notes, dated 1822; lecture notes for some of his very early lectures from 1816 to 1819—all in his own handwriting. I need hardly say—the journal of his tour in France and Italy with Sir Humphry Davy; various papers in one group with his own index to them; researches by Sir Humphry on nitrous oxide and other things. The interest of this particular volume lies in this, that it is marked by Miss Barnard: "Bound by Michael Faraday." He was as a lad apprenticed to a book-binder and stationer, and from time to time through his life, as a matter of interest and recreation, he would take up a book and bind it simply as a diversion. This one was bound by him. Then among the letters probably the most interesting group is: "Group of autograph letters of Michael Faraday with their answers, or those to which his are answers." Then in "Foreign Correspondence" we have letters to Faraday from 1821 to 1861. The writers comprise very nearly all the best-known names in science of the last century. Again similarly with the "English Correspondence." With regard to Whewell's letters, I should say that that particular group of letters has been presented by me to Trinity College, Cambridge. I found that the College had Faraday's letters to Whewell and were very desirous of having Whewell's replies to Faraday. The matter treated of in them was the nomenclature suitable for modern electrical and magnetic science. Faraday, knowing himself not to be a classical scholar, relied upon Whewell's assistance in deciding upon names, and as a matter of fact I believe the decision was so good that those names have practically been adopted to this day. There is a group of papers handed by Miss Barnard to Mr. Mordey for his examination, and returned by him to me after Miss Barnard's death. There is a group of letters from Lord Kelvin, Clerk Maxwell, and Mr. Morse, which have been seen by Professor Thompson. There is a group of letters quoted by Dr. Bence Jones in his "Life"; a group of papers on table-turning and spiritualism, the wrapper being marked by Faraday himself as "Strange Notices"; a group of papers seen by Mr. Mordey, including many notices on scientific work in Faraday's own handwriting; a group of obituary notices collected by Mrs. Faraday, but no unique interest attaches to them. In addition to the papers I have here a group of lines and records from his magnetic experiments—some of the original records. This particular group was exhibited in the Royal Institution Library, I think it was on the evening of the Centenary of Faraday. Then there is a little piece of prismatic colouring marked on the back: "Michael Faraday, Esq., with J. P. Gassiot's respects." I have also put on the table two or three photographs from my own collection—two of Faraday and two of Miss Jane Barnard, his niece, the donor of these papers. In conclusion, I should like to say that I have been very greatly aided by Mr. Mordey over a period of some two years, I

Mr. Blaikley.

Mr.  
Blaikley

think, since we began this work, and latterly by Professor Silvanus Thompson. To those two Members of the Institution I take this opportunity of tendering my most grateful thanks.

[LIST OF BOOKS, MANUSCRIPTS, CORRESPONDENCE, AND OBJECTS RELATING TO MICHAEL FARADAY, PRESENTED BY MR. D. J. BLAIKLEY.

*Printed Matter.*

DAVY, H. Researches, chemical and philosophical, chiefly concerning nitrous oxide, etc., 1800. (Marked "bound by M. F.")

A volume of pamphlets "On dry rot in timber," 1833).

A collection of pamphlets on electricity and magnetism, presented by the authors to Faraday and annotated by him.

A collection of pamphlets and extracts from periodicals containing obituary notices and eulogies on Faraday (1807-73).

*Manuscripts (bound).*

Common-place book (Miscellaneous matter, 1816-46).

Journal (France and Italy, 1813-14. Geological notes, Isle of Wight, 1824).

Chemical notes, hints, suggestions, and objects of pursuit, 1822.

Lecture notes (Chemical and physical, 1816-19).

Foolscap copy-book containing rough notes, dated 1854, and the copy of a letter addressed to Professor Tyndall, dated 6 October, 1855.

*Manuscripts (unbound).*

A collection of miscellaneous and scientific notes.

*Correspondence.*

A large collection of correspondence, chiefly scientific, with eminent English and foreign scientists (1816-66).

A selection of the correspondence quoted by Dr. Bence Jones in his "Life of Faraday" (1829-58).

Correspondence relating to Faraday's pension (1835, etc.).

Correspondence relating to table turning, spiritualism, etc. (1853-64).

Correspondence relating to Faraday's house at Hampton Court (1858).

*Objects.*

Twelve specimens of Lines of Magnetic Force, delineated by means of iron filings (framed).

A plate of prismatic colours in circular frame, inscribed on the back "Michael Faraday, Esq., D.C.L., F.R.S., with J. P. Gassiot's respects, Clapham Common, 20 January, 1840."

ALSO, PRESENTED BY MR. MORDEY:

Scientific notes (1809-10).

Bar of "heavy" glass used by Faraday.]

Professor  
Silvanus  
Thompson.

Professor SILVANUS P. THOMPSON: The Institution would at any time deem itself fortunate to be the recipient of a legacy such as this, consisting of the scientific correspondence, foreign journal, and note-books, draft lectures,

Professor  
Silvanus  
Thompson

and so forth, of that great man Michael Faraday. We honour him in our Institution as the real founder of the principles of all electric engineering. We honour the man to whom we owe the first electromagnetic motor, the first transformer, the first dynamo—in its most primitive form of the magneto-electric machine. The name of Michael Faraday, which we revere, we shall the more esteem, the more we make acquaintance with his work and with his words. It is, however, a special privilege that we who are present to-night enjoy, in that we have had these invaluable relics of the great pioneer presented to us personally by one who not only knew him intimately in younger life, but also was so immediately connected with him by his marriage to Faraday's niece. Having that privilege of the direct link with Faraday such as none other than Mr. Blaikley could have afforded us, as well as the privilege of receiving personally through his hands this unique gift, we cannot do less than accord to him, as the Council already has done, a most cordial vote of thanks. I have here a letter which a few weeks ago Mr. Blaikley addressed to the Council of the Institution, making known his desire, privately made known to us before, of handing over to us, under trust from Miss Jane Barnard, these Faraday relics. I will not now read this letter, because I imagine it will appear in our *Journal*; and, moreover, Mr. Blaikley has already mentioned the substance of it. It describes under what excellent conditions and with what exquisite goodwill this bequest has been made over to us. Mr. Blaikley has gone over the various items of this gift, so that there is no need for me to refer in detail to all of them, but I should like to make a few remarks concerning one or two items. In the first place there is the journal of the Continental voyage which Faraday, at the age of 22, undertook as assistant to Sir Humphry Davy. He went with him through France, at a time when England was actually officially at war with France. Landing in France in 1813, they travelled through France, Italy, Switzerland, and the turbulent Kingdom of Naples, which then was no part of official Italy. The diary tells how he, attached to the person of Sir Humphry Davy, was thus meeting eminent scientific men, helping Davy in chemical and electrical experiments which he showed to those scientific men, and learning languages by contact and not as a school-boy from a mere schoolmaster or from books. This diary is of exceeding interest. The plums of it have all been picked long ago, and are published in the "Life and Letters" written by Dr. Bence Jones in 1871. But there are a few things in that diary that even Dr. Bence Jones did not succeed in transferring to print, and some day I hope—possibly by this Institution—the complete story of that travel may be published. For Faraday the voyage was eventful, for it educated him in many ways; it transformed him, from being apparently little more than a grown-up book-binder's apprentice and laboratory assistant of a great chemist, into a man who could speak and think and work scientifically. That foreign tour, lasting 18 months, was for Faraday what residence at a university is for many other men; and it probably was more to him than university residence is to most men of to-day. We are now the possessors of that manuscript journal. Then there are a number of miscellaneous scientific notes of researches beginning about 1822, that eventful time when Faraday still considered himself a chemist and was

Professor  
Thompson.

discovering new and useful substances, as for instance benzol, the foundation of so many developments in industrial chemistry. If Faraday had never touched electricity he would be celebrated as a great discoverer in chemistry. There is here also a miscellaneous collection of lectures, papers, and pamphlets, of which I should like to mention one. When some 17 years ago I was endeavouring to put together a somewhat shorter biography of Faraday, I discovered that among the things which Faraday had done was to produce a pamphlet—the publisher (John Weale), the year (1833), and the title “On the Practical Prevention of Dry Rot in Timber” were all known. Naturally I wanted to see this pamphlet. They had no copy at the Royal Institution; they had no copy at the Royal Society; there was no copy in the British Museum; I could find no copy at the Institution of Civil Engineers; there was none in our Library here; in vain did I search for that pamphlet. Eventually, about three years ago, there fell into my hands a bundle of pamphlets on “Dry Rot,” and to my delight I found there was one in it by Faraday, the one I was hunting for. As a book collector I was of course proud to possess what I believed to be the only copy. My pride is now humbled; for there is a second copy here. Here is another interesting batch of documents, unimportant in themselves, but very delightful to those who revere the memory of Faraday, relating to a curious correspondence between Sir James South and, I think, the Secretary of Lord Melbourne, on the subject of Faraday’s Civil List pension. Faraday, in 1835, having then made his great electrical discoveries, or most of them, was recommended to the First Lord of the Treasury for a Civil List pension. The First Lord, in an irascible moment of the interview which he accorded to Faraday, said he did not believe in this granting of pensions to scientific men—it was all humbug; and he put in front of the word “humbug” a participle, which Faraday himself described as “theological.” Thereupon Faraday, with an instant flash of indignation, bowed and withdrew, and wrote the same evening saying that he could not possibly think of accepting a Civil List pension at the hands of one who held such sentiments. Eventually the thing was settled by the mediation of friends, and a Civil List pension was granted to Faraday, small enough, as Civil List pensions generally are; but it enabled him, with his slender salary of £100 a year and rooms and coals at the Royal Institution, to conduct his life under fairly comfortable circumstances during those strenuous years when he was building up the fame of the Royal Institution. In conclusion I wish to convey the most grateful thanks of the Institution to Mr. Blaikley, in his capacity of trustee, for handing over these treasures to us, and for his graceful courtesy in presenting them himself in person to-night.

Mr. W. M. MORDEY: I do not think I could do better than formally second the vote of thanks that has been so eloquently moved by Professor Thompson, who is our chief authority on Faraday, if only from his book on Faraday’s works and life. All who have read that book, even if they have read nothing else on Faraday, must have learnt to love him. But I must say a few words. My own part has been a very interesting one in advising Miss Jane Barnard and Mr. Blaikley as to the disposition of these papers and books. They cover a good deal of ground. They relate not only to electricity but to chem-

istry and to many other subjects of scientific and general interest. One thing which impressed me as particularly interesting was Faraday’s researches into the subject of so-called spiritualism, and his careful scientific investigation into the claims of the people who called themselves spiritualists. I hope those researches will some day be published by the Institution; I hope indeed that the Institution, in happier times, will find itself able to publish a sort of Fourth Volume of the “Experimental Researches,” comprising the more interesting parts of this collection. I should like to say, too, how grateful I am for having had the opportunity of meeting and knowing Miss Jane Barnard, the gentle old lady who had lived so many years at the Royal Institution and elsewhere with Faraday and his wife—through all those years when Faraday was doing his great work. Professor Thompson has referred to the smallness of Faraday’s pay, reckoned in money. In Professor Thompson’s book there are some verses on Faraday by Cosmo Monkhouse, one line of which I may recall—“He loved the labour better than the wage.” I am glad to have the honour of seconding this vote of thanks.

The resolution was carried by acclamation.

Mr. D. J. BLAIKLEY (*in reply*): It has given me great pleasure to be here this evening, and to have the opportunity of presenting these books and papers. I do not think I need add anything to what I have already said, except to say how grateful I am to the Council for the kind way in which they have received this gift. I should like, however, to mention that I find I omitted in the letter to the Council one thing which I had meant to say, namely, that any rights connected with the publication should certainly remain with the Council, if they see fit to publish any or all of the scientific notes of Faraday or his journal records. I should most heartily rejoice in seeing the things in print; I reserve nothing whatever in the matter; I leave everything in the hands of the Council. To those who have copies of his experimental researches it would certainly be convenient to have another volume in somewhat similar style. I merely follow up the suggestion already made in that respect, and heartily concur in it.

Mr. W. M. MORDEY: I ask your permission to intervene for a very short time before we have the pleasure of listening to our new President’s Address. I want to return to this Faraday collection two things that belonged to it which Miss Jane Barnard insisted that I should have. I accepted them with a reservation to which I now give effect, that they should only be mine temporarily and that they should go eventually to the Institution of Electrical Engineers. One of the things is the earliest record of Faraday’s scientific inclinations—I need not put it higher than that—in the form of a “Miscellany” collected by him, entirely in his own writing, in the years 1809 and 1810. He was then an apprentice; he had served five years of his seven years’ apprenticeship as a book-binder. This collection is interesting, not on account of any original matter in it, for it contains none, but because it shows the habit of industry of the man, or the boy—he was little more than a boy at that time, being 18 or 19 years old. It contains extracts from various sources on various scientific matters that had attracted his attention. We know that he was in the habit of reading the scientific

Mr.  
Mordey.

Mr.  
Blaikley.

Mr.  
Mordey.

works that came into his hands to bind, and it is very likely that many of these extracts were copied by him from those works. It has always seemed to me to be very interesting and significant, that of two great early workers in electricity, one, Michael Faraday, was a working book-binder, and the other, Benjamin Franklin—who died the year before Faraday was born—was a working printer.

The other thing which I offer for your acceptance is of greater interest. It is a small bar of glass with which Faraday made two discoveries of great but perhaps not of equal interest or importance. All students of his "Experimental Researches" know of his work on what he called his "heavy glass." For several years from 1825 he worked with the object of making glass for optical purposes with certain special properties, and he produced this "heavy glass." The work, long continued as it was, was not a success optically. Years afterwards, however, in 1845 he returned to the subject, and made two great discoveries with this glass. He had long had in his mind the belief that there must be some connection between light, electricity, and magnetism. He made many experiments, but he failed to find any connection. But in 1845 he took the matter up again and after experimenting with electricity without success, he turned to magnetism. With the big electromagnet at the Royal Institution, and afterwards with a still larger one he got from Woolwich, he discovered the relation for which he sought. He says in his "Experimental Researches," describing an experiment with a piece of this heavy glass 2 in.  $\times$   $\frac{1}{2}$  in.  $\times$   $\frac{1}{2}$  in.—perhaps this very piece—"It was this glass which first gave me the discovery of the relation between light and magnetism, and it has power to illustrate it in a degree beyond that of any other body."\* Most of you will remember the experiment—he found that the plane of polarization of a beam of light sent through this glass was rotated when magnetic lines of force were passed through the glass. Well might he say, as he did in his laboratory note-book after a strenuous day's work on that discovery: "An excellent day's work!" The second discovery is described in his "Experimental Researches," where he again refers to results obtained with a piece of "heavy glass" of this size: "Here we have a magnetic bar which points east and west in relation to the North and South Poles."† He had with this glass discovered dia-magnetism. I have very great pleasure in handing these two things back to the collection from which they came.

The CHAIRMAN: The thanks of the Institution have been already accorded to Mr. Mordey by the applause with which his remarks have been greeted, but I put it formally that we thank him for this generous gift to the Institution.

The Resolution of thanks was carried by acclamation. The Premiums and Scholarships referred to in the Annual Report of the Council‡ for the year 1914-15 were then presented by the Chairman.

The CHAIRMAN: At this late hour I must be very brief in inducting to the chair the new President, Mr. Sparks. Mr. Sparks has been a Vice-President of the Institution in years gone by; he has been a Member of Council for a great many years. Therefore he is well skilled in the

conduct of the Institution's affairs, and I am quite sure that the Presidency is very safe in his hands. Mr. Sparks has done yeoman service to the Institution as Chairman of the Wiring Rules Committee, a Committee which has very frequent sittings and has done very useful work in connection with all matters of electrical wiring. I need hardly say that he is well known to members as an eminent consulting engineer, particularly as a specialist in mining work; and members also know, as I told them when I took the chair last year, what an excellent citizen he has proved himself to be, because all his three sons are now at the front, and one of them, the youngest, has been awarded the distinction of the Military Cross. Mr. Sparks is not only an old colleague of mine on this Council but also on the Main Engineering Standards Committee, and now I am glad to say he is also a colleague of mine on important Munitions Committees under the Ministry. I know from my long and intimate connection with him that the Institution has in him a President who will most worthily uphold the dignity of the chair and redound to the credit of the whole electrical profession. I have very great pleasure in asking Mr. Sparks to take the chair of the Institution.

The chair was then vacated by Sir JOHN SNELL, and taken, amid hearty cheering, by Mr. CHARLES P. SPARKS.

Mr. W. DUDDALL: I rise to propose a hearty vote of thanks to the outgoing President, Sir John Snell. Members who have seen him at the meetings know how well he has conducted the business of the Institution. We who have seen him in the Council chamber know what a great amount of work he has done during the past year, not only for the good of the Institution but for the good of our country by assisting the Government in every possible way and by trying to promote the interests of this industry with the authorities. I should like to mention that we asked Sir John to take the presidency for a second year, but owing to the fact that he was not very well and that he is engaged on such a large amount of Government work, he was obliged to decline. I have much pleasure in proposing: "That the best thanks of the Institution be given to Sir John Snell for the very able manner in which he has filled the office of President during the past year."

Mr. J. S. HIGHFIELD: It gives me great pleasure to second the vote of thanks to Sir John Snell for the work he has done for the Institution during the past year. I need hardly say that in a time of war the work of the President has been much more heavy, although much less showy, than in an ordinary year, and I think we must all be specially grateful to Sir John for all that he has done for us.

The Resolution was carried by acclamation.

Sir JOHN SNELL: In a very few words allow me to thank members for the kind vote they have just passed. It has been a very laborious year, and, as Mr. Highfield remarked, not a showy year from the President's point of view, but I do not like show. As the head of the Institution for the time being, it has been a very great pleasure to me to be able to assist the War Office and other Government Departments in the way that I believe the Institution would have wished their President to do.

The President then delivered his Inaugural Address (see page 1).

\* "Experimental Researches," vol. 3, p. 5, par. 2151 et seq.

† *Ibid.*, vol. 3, p. 31, par. 2258 et seq.

‡ *Proceedings of the Institution*, 1914, p. 103.

Sir John Snell.

Mr. Duddall.

Mr. Highfield.

Sir John Snell.

Sir John Snell.

Mr. C. H. WORDINGHAM: It is with the greatest pleasure that I rise to propose a vote of thanks to the President. It is singularly gratifying to me to have this privilege because my friendship with Mr. Sparks goes back for many years. My first acquaintance with him was, I think, in 1888 or 1889. I remember the occasion well, because I was trying then to get a job with the London Electric Supply Corporation. I have been in more or less intimate contact with Mr. Sparks ever since; and as a colleague on the Council for many years I can well endorse what was said by Sir John Snell of his untiring work for the Institution. That work will now be greater than ever, and I am sure it will be done in the same thorough and straightforward way in which Mr. Sparks does all his work. I will not detain the meeting further, but will simply move the

resolution "That the best thanks of the Institution be accorded to Mr. C. P. Sparks for his interesting and instructive Presidential Address, and that, with his permission, the Address be printed in the *Journal* of the Institution."

Dr. A. RUSSELL: After listening to this valuable and suggestive Address, I am sure members will agree with me that the guidance of the affairs of the Institution could not be in safer or stronger hands than those of our President. I have much pleasure in seconding the vote of thanks.

The resolution was carried by acclamation.

The PRESIDENT: I thank members most sincerely for the way in which they have received my Address.

The meeting adjourned at 9.45 p.m.

582ND ORDINARY MEETING, 25 NOVEMBER, 1915.

Mr. C. H. WORDINGHAM, Vice-President, took the chair at 8 p.m.

The CHAIRMAN: The President is unfortunately prevented from being here to-night, much to his regret, and I am sure ours also.

The minutes of the ordinary meeting held on 18 November, 1915, were taken as read, and were confirmed.

Messrs. A. H. Ellis and H. H. Harrison were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

ELECTIONS.

*Members.*

Brockwell, Harold Edward. Nield, Francis Andrew.

*Associate Members.*

Graves, Ernest. Wright, Charles Edward.

*Graduates.*

Bhatnagar, Jag Mahan Lal. Jenkins, John Sefton.  
Bower, Alexander McDonald. Lauder, Archibald.  
Collett, John William. Sparks, Cedric Harold.  
Templer, Guy Merson.

*Students.*

Berry, Thomas Butland. Coulthard, William Balfour.  
Brigg, John Ellwood.

*Students—continued.*

de Boissière, Eugène Ernest M. Moore, Walter.  
Ferreira, Armando Continho da M. Murray, Burnett Moir.  
Forster, Eugène. Price, Joseph Edelsten.  
Hindom, Herbert John. Raistrick, Arthur.  
Holland-Pryor, Redvers Ryde, John Walter.  
Michael C. Simmonds, Douglas Harry.  
Howard, Arthur. Smith, Fred.  
Levy, Isadore. Walker, Edwin.  
Linay, Robert Elrick Murray. Warden, Hirjibhoj Byramji.

TRANSFERS.

*Associate Member to Member.*

Caunter, Lionel George.

*Graduate to Associate Member.*

Burns, Sydney.

*Student to Associate Member.*

Da Cunha, David Batalha. Hatch, William Ashten.  
Eley, Harry John. Sykes, Adrian Francis.

*Student to Graduate.*

Bedford, Alphonse Levi. Jockel, Lauret Marshall.

A paper by Professor A. B. Field, Member, entitled "Some Difficulties of Design of High-Speed Generators" (see page 65), was read and discussed, and the meeting adjourned at 9.55 p.m.

## INSTITUTION NOTES.

## MEMBERS OF ENEMY NATIONALITY OR ORIGIN.

Representations have been made to the Council by certain members to the effect that members of enemy origin or nationality should be excluded from membership of the Institution, and replies have been sent intimating that the Council is legally advised that the only powers of expulsion which the Institution or its Council appears to have are those contained in Article 41 of the Articles of Association.

## PRESENTATION OF A COLLECTION OF FARADAY PAPERS AND OBJECTS.

An account will be found on page 114 of the presentation to the Institution by Mr. D. J. Blakley of a valuable collection of papers of Michael Faraday.

## SUGGESTIONS FOR NOTATION AND PRINTING, MADE BY THE LONDON MATHEMATICAL SOCIETY.

It is often noticed that authors write out their manuscripts for press without consideration of the difficulties which have to be overcome in setting up the type. There are many symbols in common use in written mathematics which present special complications to the compositor: the use of such symbols naturally increases the cost of mathematical printing. In addition to this expense, it is usually observed that formulæ which are troublesome to set up are also unsightly when printed.

One of the commonest difficulties is caused by the use of a horizontal bar, above a group of symbols, instead of a bracket: for example, consider the bar in  $\sqrt{ax^2 + 2bx + c}$ . In setting up this symbol, the bar has to be cut to the proper length and then to be placed in a separate line; the remainder of that line has to be filled up by "leads" \*, also cut to the proper sizes, to prevent the bar from shifting. When the page is printed, these "leads" cause an irregular spacing between the lines (see, for instance, the line above which contains the square root). But, if the square root is written as  $\sqrt{(ax^2 + 2bx + c)}$ , the effect of the brackets is merely to introduce two new pieces in the ordinary line of type; much less trouble is involved, and the spacing between the lines remains uniform.

An even greater difficulty presents itself when bars or dots are placed above or below letters in order to produce new symbols; as, for example, in  $\bar{a}, \bar{b}, \bar{c}, \bar{d}, \bar{e}, \bar{f}, \bar{g}, \bar{h}, \bar{i}, \bar{j}, \bar{k}, \bar{l}, \bar{m}$ . This kind of symbol is more difficult for the compositor than the bar in the square root symbol, because of the small size of the type carrying bars and dots and of the trouble involved in fixing it in its proper position. A further reason for avoiding bars and dots in these combinations is that the small extra pieces of type being unsupported are very fragile and so are apt to

break off; they may easily get out of place, and even a trifling slip produces confusion and an appearance of irregularity in the printed page.\*

The use of dots in dynamical work, reintroduced from the Newtonian fluxional notation by Thomson and Tait in 1868, violates this rule and the dots can usually be replaced by accents without any loss: accents are employed, for instance, in Routh's "Rigid Dynamics." A reversion from the fluxional notation is now definitely recommended; except in cases where it is convenient to use dots to denote differentiation with respect to  $t$ , and accents for differentiation with respect to a second variable (such as the arc, in the theory of curves). The use of bars as distinguishing marks could often be replaced either by suffixes or by accents; and neither of these will give any trouble in printing. The factorial symbol  $|n$  is being gradually superseded by  $n!$ , which offers no difficulty to the compositor.

When fractions have to be printed in the body of continuous matter, difficulties will again arise from the use of the horizontal bar; here the bar itself is placed in the line of type, but the numerator and denominator of the fraction have to be placed above and below the line.

Thus, in printing  $\frac{ax+b}{cx+d}$ , the numerator and denominator are held in place by two lines of small low blocks (called "spaces"); and the horizontal bar has further to be balanced by two "leads" cut to the proper lengths, extending from the fraction to the sides of the page, and placed below the second line of "spaces."

In many cases, the horizontal bar can be replaced by the solidus or slanting line  $/$ ; for example, the fraction above might be written  $(ax+b)/(cx+d)$ ; then no complication arises in printing, while the spacing between the lines remains uniform, and a considerable saving of space is effected. The solidus is particularly useful in printing fractional indices or suffixes, and in the limits of definite integrals. Thus we should always print

$$e^{-\frac{n\pi x}{l}}, \quad I_{\frac{n\pi}{a}}, \quad \int_0^{\frac{n\pi}{a}},$$

rather than 
$$e^{-\frac{n\pi x}{l}}, \quad I_{\frac{n\pi}{a}}, \quad \int_0^{\frac{n\pi}{a}}.$$

It may be useful to notice, however, that the simplest numerical fractions (such as  $\frac{1}{2}, \frac{2}{3}, \frac{3}{4}$ ) are usually cast as single pieces of type: and so we can print  $\frac{1}{2}\pi, \frac{2}{3}\pi, \frac{3}{4}\pi$ , without any more difficulty than  $2\pi, 3\pi$ , etc.

It must also be noticed that in printing equations in

\* There are two different methods of producing such symbols. With short letters (such as  $a, c, n$  in the examples given above) the top of the body of the type is cut away, and the extra type (a small rule, full stop, or colon, as may be required) is inserted into the vacant place: thus no separate line or leads need be used. But with tall letters (such as  $b, h$  in the examples), the extra type has to be fixed in a separate line, and it must then be kept in place by "leads." In either case the combination is difficult to make, and the extra type is liable to break off or get dislodged before being printed off. It is possible, it is true, to cast special types with the rule or dot affixed to the letters in question, but this would be very expensive, and in the case of the tall letters ( $b, h$ ) would produce a very fragile letter to print from.

\* That is, lengths of thin rolled lead or brass; the latter being more usual in broken lines.

separate lines, the objection to the horizontal bars of fractions is not serious, because large blocks (called "quadrats") can be used to fill up the blank spaces at the sides of the equations. It is then usually much better to use the ordinary notation on account of its greater clearness. For instance, we should write

$$\frac{x}{a} = \frac{y}{b} = \frac{z}{c} = \frac{lx + my + nz}{la + mb + nc} = \sqrt{\frac{(x^2 + y^2 + z^2)}{(a^2 + b^2 + c^2)}}$$

rather than

$$x/a = y/b = z/c = (lx + my + nz)/(la + mb + nc) = \sqrt{(x^2 + y^2 + z^2)/(a^2 + b^2 + c^2)}$$

It is often convenient to introduce separate lines of formulae in the middle of a long paragraph: in such lines, there is no reason for using the solidus: and the ordinary notation for fractions would preferably be used. It should also be remembered that an extensive use of the solidus is apt to be confusing to the reader: and when several fractions come close together in a paragraph, it is usually worth while to set them out on a separate line, using the ordinary notation, and putting the intervening words on the same line. An example of this arrangement will be found in the line of fractions used in the next paragraph.

Ambiguity in the meaning of symbols containing the solidus may be removed by the use of brackets; but combinations such as  $p/(q + rs)$  and  $(p/q + r)/s$  are generally found difficult to read, and might be replaced either by

$$\frac{p}{q + rs} \text{ and } \frac{p/q + r}{s}, \text{ or by } p/\left(q + \frac{r}{s}\right) \text{ and } \left(\frac{p}{q} + r\right)/s.$$

The value of the solidus is largely discounted when, through want of attention, its use is pushed to unsightly extremes.

It may be well to say explicitly that the affixing of indices, suffixes, or accents involves none of the complications already mentioned; at least so long as superposed indices or suffixes are avoided. Thus it is easy to print

$$1 + x + x^2 + x^3, \quad y_1 + y_2 + y_3, \quad \Sigma a_n^n, \quad f'(x),$$

although difficulties as well as unsightliness arise with symbols like

$$g^{28} \text{ and } a_{n+2}.$$

in each of which special lines have to be built up with "quadrats" and "spaces," so as to hold in place the extra indices and suffixes.

For convenience of reference the foregoing remarks have been summarized and illustrated in the following tables of equivalent symbols.

<i>Instead of</i>	<i>Always print</i>
$\sqrt[3]{2}, \quad \frac{1}{\sqrt[3]{2}}, \quad \sqrt[3]{13}$	$\sqrt[3]{2} \text{ or } 2^{\frac{1}{3}}, \quad 1/\sqrt[3]{2} \text{ or } 2^{-\frac{1}{3}}, \quad \sqrt[3]{13} \text{ or } 13^{\frac{1}{3}}$
$\sqrt{ax^2 + 2bx + c}$	$\sqrt{ax^2 + 2bx + c}$
$\sqrt{\frac{a}{b}}$	$\sqrt{a/b} \text{ or } (a/b)^{\frac{1}{2}}$
$\sqrt[3]{-1}$	$\sqrt[3]{-1} \text{ or } -1$

<i>Instead of</i>	<i>Always print</i>
$n, \quad \frac{n}{n+1}, \quad \frac{n}{n-2}$	$n(n+1)(n+2)$
$(1)^n, \quad  n+1, \quad  2n, \quad 2^n  n$	$(n!)^2, \quad (n+1)!, \quad (2n)!, \quad 2^n  n!$
$x, \quad \dot{x}, \quad i, \quad \ddot{0}$	$x', \quad \dot{x}, \quad i', \quad \ddot{0}'$ (by preference)
$\frac{a}{2}, \quad \frac{a+b}{3}, \quad \frac{a+b+c}{4}$	$\frac{1}{2}a, \quad \frac{1}{3}(a+b), \quad \frac{1}{4}(a+b+c)$
$\frac{a+b}{c}, \quad \frac{a}{b+c}, \quad \frac{a}{b} + c$	$(a+b)/c, \quad a/(b+c), \quad a/b + c$
$\frac{p}{q}, \quad \frac{p}{q} + \frac{r}{s}, \quad \frac{p}{p/(q+rs)}$	$p/q, \quad p/q + r/s$ (in current text)
$\frac{p}{q} + \frac{r}{s}$	$\frac{p}{q} + \frac{r}{s}$ or $p/\left(q + \frac{r}{s}\right)$
$\frac{1}{x}, \quad \frac{1}{x^n}$	$1/x \text{ or } x^{-1}, \quad 1/x^n \text{ or } x^{-n}$
$\frac{p + \frac{q}{2}}{\frac{r}{3} + \frac{1}{4}}, \quad \frac{x}{y + \frac{z}{t}}$	$\frac{p + \frac{1}{2}q}{\frac{1}{3}r + \frac{1}{4}}, \quad \frac{x}{y + z/t}$
$e^{-\frac{\pi x}{t}}, \quad e^{-\frac{x^2}{4\pi t}}$	$e^{-\pi x/t}, \quad e^{-x^2/4\pi t}$
$I_{\pi}, \quad \int_0^{\pi}, \quad \int_0^{\pi}$	$I_{\pi}, \quad \int_0^{\pi}, \quad \int_0^{\pi}$
$(2/l) \int_0^l \sin(\pi x/l) \sin(s\pi x/l) dx$	$\frac{2}{l} \int_0^l \sin \frac{\pi x}{l} \sin \frac{s\pi x}{l} dx$

\* It may be noted that an integral with limits always involves a double line: so that the ordinary notation for fractions involves no additional use of "spaces" beyond those required for the integral in any case.

## MEMBERS ON MILITARY SERVICE.

### (FIFTH LIST.)\*

<i>Name.</i>	<i>Corps, &amp;c.</i>	<i>Rank.</i>
Andrews, G. L.	Royal Garrison Artillery	Lieutenant
Bell, H.	1/3rd Northumbrian Field Co., R.E.	Captain
Bruce, G. A.	Royal Marines	Major
Cadman, C. G.	Malay States Volunteer Rifles	Private
Caldwell, J.	3/6th Argyll and Sutherland Highlanders	2nd Lieut.
Chartres, C. B.	Calcutta Port Defence Volunteers	2nd Lieut.
Covernton, R. H.	South African Engineer Corps	Lieutenant
Day, B. J.	Glamorgan Yeomanry	Captain
Holmes, R. J. M.	Northumbrian Divisional R.E.	2nd Lieut.
Jenkin, Prof. C. F.	R.N.V.R.	Lieutenant
Marconi, G.	Italian Army Engineers	Lieutenant
Paterson, S.	Royal Engineers	2nd Lieut.
Raphael, F. C.	Anti-Aircraft Corps (R.N.A.S.)	Able Seaman
Sayers, H. M.	Anti-Aircraft Corps (R.N.A.S.)	Able Seaman
Shields, J. C.	2nd Calcutta Presidency Rifle	Cyclist

\* See Vol. 53, pp. 102, 126, 188, and 847.

MEMBERS—continued.		
Name.	Corps, etc.	Rank.
Taylor, W. T.	1/23rd Royal North Lancashire Regt.	Captain
Thomson, H. L.	Army Service Corps	Captain
Tyson-Wolfe, H. L.	East Indian Cavalry Volunteer Rifles	Private
Wilson, R. P.	Anti-Aircraft (R.N.A.S.) Corps	Able Seaman
Wimperis, H. E.	R.N.V.R.	Lieutenant

## ASSOCIATE MEMBERS.

Aldous, F. C.	6th Manchester Regt.	Captain
Baker, A. C.	Royal Naval Air Service	Air Mechanic
Barton, R. G.	Royal Naval Air Service	Petty Officer
Bradbury, W. H.	Calcutta Volunteer Rifles	Private
Brook, R. V. C.	R.N.V.R.	Lieutenant
Bruce, R.	Royal Engineers	Lieutenant
Bullard, F. R.	2/1st Derbyshire Yeomanry	2nd Lieut.
Clarke, A. E.	6th Manchester Regt.	Sergeant
Coates, W. H. C.	Royal Field Artillery	2nd Lieut.
Colbeck, P.	6th Northumberland Fusiliers	Captain
Coxon, J.	Royal Engineers	Lieutenant
Cramer, F. B.	Royal Marines	Captain
Edridge, W. H.	Army Service Corps	1st Class War-rant Officer
Farrell, U. A.	Royal Navy	Chief Petty Officer
Findley, G. F.	Royal Garrison Artillery	Instructor in Field Tele-graphy and Telephony
Fleming, E. W.	6th Cameron Highlanders	Corporal
Francis, R.	London Electrical Engineers.	Sergeant
French, W. E.	17th West Yorkshire Regt.	Lieutenant
Garland, C. C.	Divisional Engineers, R.N.D.	Sapper
Gilling, A. C.	Royal Flying Corps	2nd Lieut.
Hamilton, C. N. M.	Royal Garrison Artillery (S.R.)	2nd Lieut.
Hasdell, J. S.	Royal Flying Corps	2nd Class Air Mechanic
Hayward, C. H.	R.N.V.R.	Lieutenant
Helme, G. S.	Highland Brigade, R.F.A.	2nd Lieut.
Hoyle, L. A.	Honourable Artillery Com-pany	Private
Hunt, T. C.	Royal Engineers	2nd Lieut.
Jager, H. T.	Cossipore Artillery Volunteers	Gunner
Lloyd, J.	Jamaica Reserve Regt.	2nd Lieut.
Lockwood, A.	6th Royal Welsh Fusiliers	Private
Low, A. R.	R.N.V.R.	Lieutenant
McLoughlin, H. F.	10th East Lancashire Regt.	2nd Lieut.
Martin, L. C.	London University, O.T.C.	Cadet
Meredith, J.	Inns of Court O.T.C.	Private
Moberly, R. M.	East Riding (Fortress) R.E.	2nd Lieut.
Neate, E. P.	Royal Engineers	2nd Lieut.
Parker, C. E. F.	2/2nd Monmouthshire Regt.	2nd Lieut.
Parkinson, J.	Royal Engineers	Lieutenant
Perry, C. S.	Inland Water Transport Corps, R.E.	Lieutenant
Phillips, N. D. B.	Glamorgan (Fortress) R.E.	2nd Lieut.
Pink, H. W.	Hampshire (Fortress) R.E.	2nd Lieut.
Pope, W. G. T.	Royal Engineers	2nd Lieut.
Powell, C.	Lowland Divisional R.E.	2nd Lieut.
Powell, H. W.	Royal Naval Air Service	Petty Officer
Preece, G. G. L.	Lancashire Fusiliers	2nd Lieut.
Pysier, M. E.	Royal Engineers	Sapper
Ransom, S.	Royal Flying Corps (Wire-less Section)	2nd Lieut.

ASSOCIATE MEMBERS—continued.		
Name.	Corps, etc.	Rank.
Robertson, H.	Army Service Corps	Sergt.-Major
Russell, R. P.	Royal Engineers	2nd Lieut.
Salt, C. W.	London Electrical Engineers.	Sapper
	R.E.	
Saner, E. J.	2/5th Bedfordshire Regt.	Captain
Sanger, P. M.	1st Honourable Artillery Com-pany	Private
Sargent, G. H.	Army Service Corps	2nd Lieut.
Smith, W. Balfour	Royal Flying Corps	2nd. Class Air Mechanic
Smyth, A. H.	Army Ordnance Dept.	Lieutenant
Stelling, A. R.	3/1st North Midland Divisional R.E.	2nd Lieut.
Stiell, E. J.	Royal Engineers	2nd Lieut.
Sutthery, F. B. C.	Tyne Electrical Engineers.	Lieutenant.
	R.E.	
Tronche, J.	French Army	Brigadier
Trust, H. G.	Intelligence Corps	2nd Lieut.
Tufnell, H. C. C.	London Electrical Engineers.	Captain
	R.E.	
Unwin, F. R.	Royal Engineers	Lieutenant
Wall, Dr. T. F.	R.N.V.R.	Lieutenant
Ward, E. J.	3rd Royal Irish Regt.	2nd Lieut.
Watson, H.	9th Scottish Provisional Batt.	Corporal
Wilson, G. H.	Royal Engineers	2nd Lieut.

## ASSOCIATES.

Cottrell, W. H.	R.N.V.R.	Commander
Foinette, Rev. T. W.	Army Ordnance Corps	Private
Lawrance, N. McL.	2/4th East Anglian Brigade, R.F.A.	2nd Lieut.
Nettley, C. N.	Royal Naval Air Service	Chief Petty Officer
Rosevere, G. R.	Army Ordnance Dept.	Lieutenant
Simpson, L. S.	Royal Engineers	Captain
Vickerman, M. H.	Army Service Corps	2nd Lieut.
Watson, C. L.	Royal Engineers	2nd Lieut.

## GRADUATES.

Bamford, H. M.	Divisional Engineers, R.N.D.	Lieutenant
Black, E. G.	Royal Naval Reserve	Eng. Lieut.
Butler, H.	11th Yorkshire Regt.	2nd Lieut.
Curling, H. W.	Army Service Corps	2nd Lieut.
Dainty, W. R.	Royal Naval Air Service	Flight Sub-Lieut.
Gray, R.	Royal Field Artillery	2nd Lieut.
Groom, H. R. L.	1/5th Royal Warwickshire Regt.	2nd Lieut.
Hilder, W. T.	London Electrical Engineers.	Sapper
	R.E.	
Jones, E. F.	Royal Field Artillery	2nd Lieut.
Laird, S. A.	Royal Flying Corps	2nd Lieut.
Niblos, F. J. McC.	London Electrical Engineers.	Sapper
	R.E.	
Richardson, T. C.	Royal Engineers	Captain
Sparks, C. H.	Royal Field Artillery	Lieutenant
Wall, W. G. P.	Naini Tal Volunteer Rifles	Private
West, F. W. J.	Royal Bucks Hussars	Trooper

## STUDENTS.

Andersen, R. C.	London Divisional R.E.	2nd Lieut.
Baxter, W. M.	Royal Naval Air Service	Mechanic
Berv, T. B.	Royal Engineers	2nd Lieut.
Best, J. A. A.	London Electrical Engineers.	Sapper
	R.E.	
Birch, E. E.	Royal Naval Reserve	Sub-Lieut.

## GRADUATES.

Name	Corps, etc.	Rank
Bunt, C. L.	4th Duke of Cornwall's Light Infantry	Lieutenant
Chalmers, J. W. P.	Royal Engineers	Lieutenant
Cheshire, I.	3rd Manchester Regt.	Private
Cole, N. H.	Royal Flying Corps	2nd Class Air Mechanic
Cosens, C. R.	Royal Engineers	Lieutenant
Cross, W. G.	13th Liverpool Regt.	Sergeant
Dawes, A. R.	London Electrical Engineers R.E.	Sapper
Dawes, R. R.	6th Manchester Regt.	
Dennis, B.	University of London O.T.C.	Cadet
Derry, C.	Army Service Corps	2nd Lieut.
Edwards, W. G.	Tyne Electrical Engineers R.E.	2nd Lieut.
Gall, D.	Royal Naval Air Service	Sub-Lieut.
Glover, E. H.	Royal Engineers	2nd Lieut.
Gripper, L. A.	Royal Army Medical Corps	
Harris, L. E. H.	26th Batt., Australian Force	Lance-Corpl.
Haves, L. W.	Royal Naval Air Service	Petty Officer
Heves, F. J.	Royal Anglesey R.E.	2nd Lieut.
Holland-Pryor, R. M. C.	Royal Navy	Sub-Lieut.
Johnson, W. G.	Royal Engineers	2nd Lieut.
Jones, J. W.	East Lancashire R.E.	2nd Lieut.
Kerman, W. H. P.	Royal Naval Air Service	1st Class Air Mechanic
Keith, C. H.	Royal Naval Air Service	Lieutenant
Killingback, S. G.	Royal Engineers	2nd Lieut.
King, L. S.	London Electrical Engineers R.E.	Sapper
Lawrence, F. C.	14th West Yorkshire Regt.	2nd Lieut.
Lee, J. H.	24th Yorkshire Regt.	2nd Lieut.
Leaves, A. H.	3/1st East Lancashire R.E.	2nd Lieut.
Lloyd, W. F.	London Electrical Engineers R.E.	Sapper
Low, D. W.	R.N.V.R.	Lieutenant
Mabbs, E. G.	Royal Army Medical Corps	Private
McMahon, V. H. M.	Army Service Corps	Staff Sergeant
Manlove, C. W. W.	Kent (Fortress) R.E.	2nd Lieut.
Mann, R. R. G.	Royal Engineers	2nd Lieut.
Moody, H. T.	London Electrical Engineers R.E.	Sapper
Murray, L. E. R.	Royal Naval Air Service	Flight Sub-Lieut.
Padgett, A. S.	6th Manchester Regt.	Private
Pock, L. C.	Anglo-Russian Hospital	Orderly and X-Ray Asst.
Rawlings, W. J.	London Electrical Engineers R.E.	2nd Lieut.
Rendle, G. A.	14th Royal Fusiliers	2nd Lieut.
Shaw, W. H.	Royal Engineers	Corporal
Shiell, R. A.	1st London Scottish	Private
Smith, C. P.	London Electrical Engineers R.E.	Sapper
Stainer, W. W.	Royal Sussex Regt.	2nd Lieut.
Taylor, C. R. F.	Royal Flying Corps	2nd Class Air Mechanic
Tolley, C. E.	Wessex Divisional R.E.	
Welch, J. G. L.	Royal Garrison Artillery (S.R.)	2nd Lieut.
Yeates, A. C.	Royal Navy	Eng. Lieut.
Young, H. V.	Inns of Court O.T.C.	Private

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## THE DESIGN OF HIGH-PRESSURE DISTRIBUTION SYSTEMS.

By J. R. BEARD, M.Sc., Associate Member.

*(Paper first received 20 February, and in final form 9 October, 1915; read before THE INSTITUTION 10 December, before the WESTERN LOCAL SECTION 13 December, and before the MANCHESTER LOCAL SECTION 14 December, 1915.)*

### INTRODUCTION.

The general distribution of electrical energy to individual consumers at high pressures is of comparatively recent development, one of the first schemes in this country being that which was inaugurated in the year 1901 for the purpose of supplying power to shipyards on the Tyne and which has since grown into the extensive system that now covers the principal industrial districts of Northumberland, Durham, and North Yorkshire. High pressures had previously been used, but only for transmission purposes to enable the power stations to be situated outside the areas of supply in order to utilize special advantages such as waterfalls, cheap sites, plentiful condensing water, or easy delivery and storage of coal. In such cases the high-pressure energy was transmitted to a point near the centre of the area of supply, where the whole of it was transformed to low pressure for distribution to the consumers. Such schemes, for example, were Dr. Ferranti's pioneer high-pressure transmission from Deptford to London, and various water-power schemes in America and on the Continent.

The advantages of supplying concentrated power loads, of say 100 kilowatts and over, direct from the power station at high pressure and transforming to the working voltage at individual sub-stations adjacent to the load centres, have since been generally realized, and the last decade has seen an enormous development both in the number and in the size of such high-pressure distribution systems. Side by side with the development of high-pressure distribution for power purposes, similar methods were found essential for the various railway electrification schemes, and also for the supply of power to the larger tramway systems which were spreading out over an area that it was impossible to supply at low pressure from a single power station. Up to the present the method of distribution for lighting has not been radically altered, although occasionally the existence of a high-pressure distribution system, primarily installed for other purposes, has resulted in bulk supplies

being given to outlying districts. It is, however, being more generally realized that only under exceptional circumstances is it possible to find near the centre of a large lighting load conditions which permit of economical generation, and consequently the original Deptford example is being more widely followed. In many such cases, owing to the ease with which a sub-station—unlike a power station—can be installed in almost any position, there is a growing tendency to split up the more extensive and cumbersome low-pressure networks into several sections, each fed by a separate sub-station. As the use of electricity for lighting and other domestic purposes increases, there is little doubt that these sections will gradually decrease in area, with a consequent increase in the number of high-pressure feeding points, so that in this, as in other branches of electricity supply, the distribution will eventually be at high pressure practically to the consumers' terminals.

Not only is the cost of distribution at high pressures considerably less than at low pressures, but also it is thus possible for a single power station to supply economically over an enormously greater area than that which was previously practicable, and in consequence by better diversity factor and larger and more efficient generating plant great reductions have been effected in the cost of electricity. The maximum economy from these advantages is still far from being obtained, and there is therefore every prospect that in the future the growth of high-pressure distribution systems will be equally as rapid as it has been in the past. The growth should, however, be in size and not in number, since in order to reap the full benefit of improved diversity factors and increased efficiency of generation it is essential that each system should supply the whole of the demands of the area which it serves, and also that the area served should be as large as possible.

The term "distribution system" is often used in a broad sense to indicate everything outside the power station, but in the present instance it will be restricted to mean the mains which convey the electrical energy from the power stations where it is generated to the sub-stations where it

is transformed to a form suitable for the consumers' use, together with the switchgear controlling them. The paper will further be limited to a consideration of 3-phase alternating-current systems, as it is generally recognized that these are most suitable for high-pressure distribution.

#### GENERAL PRINCIPLES.

A well-designed distribution system is that which secures the following essential characteristics at a minimum total annual cost :—

- (a) Safety in operation both as regards the operating staff and the public generally.
- (b) Suitability of the supply for the purposes for which it is required.
- (c) Freedom from interruption of supply.

Safety in operation is of primary importance, since with high pressures accidents are frequently fatal and, in this country at any rate, no commercial advantage is considered sufficient to justify unnecessary danger to human life.

The other two limitations have a commercial basis. In all its various uses electricity is a competitor with other forms of energy, many of them very firmly established, and if it is not supplied in suitable form, or if the supply is subject to interruption, the sale of it will be restricted. For example, the cost of power is such a small proportion of the total cost of running a works that material irregularity in the supply would quickly involve more loss than the whole cost of the power bill. In such circumstances a supply of electricity would not be a paying proposition if it could be obtained for nothing.

Failure of supply is usually caused by the breakdown of apparatus, and the primary precaution is therefore careful attention to the design, manufacture, and maintenance of the various parts of the system; but since no apparatus can be made absolutely immune from breakdown through external damage, the secondary precaution is to make arrangements so that the effects of a breakdown to any part of the system are localized as much as possible. In some cases such precautions may mean increased capital cost, but they undoubtedly result in a net economy if a broad view is taken. Fortunately, however, well-designed apparatus does not necessarily cost more than badly designed apparatus, and, as will be seen later, it is possible to cheapen the system by closer localization of breakdowns.

The chief items which make up the annual cost are the following, and it is the sum total of these which should be a minimum :—

- (1) Interest on capital expenditure.
- (2) Repairs and provision for depreciation.
- (3) Switchgear attendance.
- (4) Energy losses in the mains.

It may be useful to consider briefly these items in turn, and to note in what ways they are interdependent and how they are affected by the essential characteristics previously detailed.

(1) It is unnecessary to say anything as to the desirability of keeping down capital expenditure; the chief danger is usually lest this should receive too much attention at the expense of other items. There is, however, a further way of reducing interest charges, namely, by a low rate of

interest, and this can only be secured by a permanent and steady business. This is a further argument for extending and consolidating the area of supply so that the revenue of the undertaking is less subject to trade fluctuations.

(2) A low cost of repairs goes hand in hand with low depreciation charges, since both depend on the permanence of apparatus and its freedom from breakdown. Money is doubly well spent on these points, since it not only reduces repairs and depreciation but provides the first precaution already postulated as necessary to ensure security of supply.

(3) Particularly in the case of static sub-stations, which have not an operating staff continually on shift, attendance is largely a matter of operating switches should a fault occur on some part of the system. Apart from cost, such attendance is often very difficult to arrange for, and there is therefore a strong reason for reducing it as much as possible. This can be done by closer localization of breakdowns so that the only part of the system which is affected is that in the immediate neighbourhood of the fault, thus at the same time taking the second precaution postulated as necessary to ensure security of supply. The cost of attendance is not only a question of amount but also of quality, and cheaper labour can be employed if apparatus is designed to prevent automatically the more serious mistakes in operation. Such design tends to increased safety in operation, which has been previously mentioned as the first essential characteristic of the system.

(4) Loss of energy in the mains can be reduced by increased capital expenditure, and it is therefore a question of the correct balance between the two. It can also be reduced by linking up the various parts of the system in order to utilize the diversity of their loads, a process only rendered possible by again using means for localizing the effects of breakdowns.

It is interesting to note that the essential characteristics of the system are not incompatible with designing it on the basis of minimum annual cost, since though they may in a few cases increase the capital expenditure this is discounted by savings in other ways.

The object of this paper is to endeavour to indicate on the basis of the preceding general principles the most suitable choice of apparatus and the means whereby that apparatus can be used to the greatest advantage. For this purpose the paper will be divided into the following sections :—

#### I. The important points in the choice of individual apparatus :—

- (a) Mains.
- (b) Switchgear.

#### II. The methods by which such apparatus may be most economically utilized, the consideration of which naturally falls into three successive stages. The basis of the investigations is :—

- (a) The determination of the economical section of mains; that is to say, the correct balance between losses and capital expenditure.

From this it is possible to consider progressively :—

- (b) The lay-out of the distribution system to give the maximum economy.
- (c) The most suitable distribution voltage.

## I(a). MAINS.

As it is desirable to avoid covering ground which has been recently covered by other papers read before the Institution<sup>2</sup> this section of the paper will be limited to a brief consideration of the conditions which determine whether underground or overhead mains are most suitable for particular cases. Both have reached a high degree of perfection, but owing to the fact that the conductors are exposed, overhead mains are necessarily more subject to breakdowns than underground mains, so that from the point of view of security of supply the latter are to be preferred, unless special circumstances such as liability to serious subsidence increase the risk of damage to cable. This point is, however, not so important as might be thought, since in spite of the numerous ways in which overhead mains can be damaged by snow, wind, lightning, malicious damage, and short-circuits due to birds, flying straw, kite strings, etc., it is found in practice from extended experience that per mile of main the average number of serious breakdowns of overhead mains is only about double that on underground mains. Overhead mains are, however, more liable to cause temporary interruptions of supply by being automatically disconnected on transitory short-circuits which do not cause permanent damage. The advantage of overhead mains is their lower capital cost, more particularly at higher voltages; this is readily seen by glancing forward for a moment to Fig. 7, which shows comparative annual costs per mile for various voltages, allowing a slightly higher figure for the maintenance of overhead mains and including a reasonable figure for wayleaves. For low voltages and small sizes there is not much to choose on the score of cost, and underground mains are therefore preferable on account of their other advantages. As the voltage and size increase, however, a considerable saving is effected by the use of overhead mains; and such saving is often increased by the difficulty of finding direct routes for cables in the open country where roads are few and winding.

While it will be seen from the foregoing that the use of overhead lines in open country is frequently fully justified, they have further disadvantages which must always be borne in mind, viz. :—

- (a) They usually require a special wayleave.
- (b) The inductive drop is much greater than that of an equivalent cable.
- (c) If overhead lines are run in parallel with cables neither can be operated at their maximum economy.
- (d) They tend to lower the power factor of the system as a whole.

(a) The objection to wayleaves is not so much their cost as the trouble and delay in obtaining them, and that they can seldom be bought outright. The anomalous and conservative provisions of English law in this matter have been recently discussed both by Mr. Welbourn in his paper on high-tension overhead lines<sup>†</sup> and by Mr. C.

Vernier in his Address to the Newcastle Local Section,<sup>\*</sup> and the matter had also been previously raised by Mr. W. B. Woodhouse as a result of his experience with the Yorkshire Electric Power Company.<sup>‡</sup> When a suitable time arrives the need for the legal changes which they advocate should not be lost sight of.

(b) The inductance of a 3-phase circuit, other factors remaining constant, varies as the logarithm of the distance between the conductors; the higher inductance of overhead lines is therefore inherent in their construction, since this distance must be many times the corresponding distance in a cable, owing partly to the lower insulating value of air as compared with impregnated paper, but more particularly to the necessity for preventing the wires being short-circuited by birds, or by unequal sagging due to wind, or by unequal sagging due to snow. This higher inductance does not affect the voltage-drop when the power factor of the system is not a lagging one, but it is unusual for the amount of synchronous plant on the system to be sufficient to ensure this. The question of voltage-drop is dealt with more fully in a later section, but by reference to Fig. 10 the increase in voltage-drop at 50 cycles with various lagging power factors is clearly shown.<sup>§</sup> It will be noted that it is quite serious, particularly in the case of heavy-section lines, and consequently the use of overhead mains means either a reduced radius of transmission for a given voltage, or extra capital cost in providing additional copper. To some extent this disadvantage is minimized by the fact that for economy overhead mains should be run at a lower current density than cables (see section on the economical section of mains and Fig. 6), and also by the fact, noted previously, that it is often possible to carry overhead lines over a shorter route than the equivalent cable.

In certain special cases the inductance of overhead mains may be of definite benefit. This is, for example, the case in continuous-current traction systems supplied by rotary converters which can be arranged to draw a leading current from the line at heavy loads. It will be seen by again referring to Fig. 10 that with quite a moderate leading power factor the total voltage-drop in an overhead line feeding a rotary-converter sub-station may be zero.

(c) If a cable and an overhead line of equal section are connected in parallel the higher inductance of the overhead line causes the total current to divide unequally between the two circuits. This not only prevents the two circuits being run at their most economical current density, but also, owing to the resistance losses being dependent on the square of the current, they are greater than if the current were divided equally. Further, owing to the difference in the inductance of the parallel circuits, there is a phase difference between the currents in the two branches. This results in the arithmetical sum of the currents in the branches being greater than the total current, thus causing additional resistance losses and a reduction in the carrying capacity of the circuits. To take a concrete example, assume that 300 amperes at 6,000 volts and 50 cycles is to be transmitted through a 0.15 sq. in.

<sup>\*</sup> *Journal I.E.E.*, vol. 52, p. 17, 1914.

<sup>†</sup> *Ibid.*, vol. 44, p. 802, 1910.

<sup>‡</sup> The curves given in Fig. 10 are calculated for ordinary 3-conductor mains. If arranged for split-conductor protection the inductive drop is reduced.

<sup>\*</sup> C. J. BEAVER, "Cables," *Journal I.E.E.*, vol. 43, p. 57, 1915.  
B. WELBOURN, "British Practice in the Construction of High-tension Overhead Transmission Lines," *Ibid.*, vol. 52, p. 177, 1914.  
C. VERNIER, "The Laying and Maintenance of Transmission Cables," *Ibid.*, vol. 47, p. 313, 1911.  
<sup>†</sup> *Ante*.

cable and a 0.15 sq. in. overhead line in parallel. The actual current in the cable will be 210 amperes, and in the overhead line 105 amperes, while the resistance losses are increased by 24 per cent as compared with the losses if both circuits were either cable or overhead line.

(d) It is at once evident that, so far as the power station and the mains back to the power station are concerned, the wattless current produced by the extra inductance of an overhead line will be as deleterious as if it were produced by consumers' apparatus.

#### I(b). SWITCHGEAR.

The following remarks are directed to the more important or novel features which should influence the choice of the most suitable apparatus for sub-station use. Similar principles apply, but with greater force, to power-station switchgear.

Switchgear fulfils several functions, but the primary one is to isolate faulty apparatus, and consequently to interrupt or prevent heavy short-circuit currents. This is the determining factor in its design. The problem is therefore one of considerable difficulty, since it is largely beyond mathematical calculation and the chief data to work upon are those obtained from actual experience. With many problems great assistance can be obtained from experiments, but this is difficult with switch design, as the conditions cannot be adequately reproduced on a small scale and it is not usually commercially practicable to risk experiments on an actual system.

As the tendency is for distribution systems to supply a denser load it follows that the maximum short-circuit current is continually increasing; for not only is there a larger kilowatt capacity of running plant on the system but also a greater number of feeds into a fault. Moreover, the conditions are further aggravated by higher distribution voltages, without any corresponding reduction in the resistance of the faults. It therefore follows that switch design is a gradual process of feeling one's way; methods which have given good service on one size of system being tried on a larger one and modifications introduced if the more onerous conditions show up weaknesses.

The breaking of a heavy short-circuit can be best likened to the detonation of an explosive, and if the switch is badly designed the tank will be blown off and the whole switch wrecked. This was at one time thought to be due to the large quantities of white-hot oil vapour generated by the arc rising to the surface, and spontaneously igniting on meeting the air. It has, however, been proved by experience that a switch designed to withstand the maximum explosive pressure of the gases may be unable to withstand a short-circuit with unlimited power behind it, and it now seems probable that the chief explosive effect is to be found in the rapid generation of gas beneath the surface of the oil. Switches for heavy duty are usually designed with air cushions and vent pipes open to the atmosphere in order to remove the gases, but these measures do not materially relieve the pressure in the tank, as apparently the inertia of the liquid causes an exceedingly high local pressure which is transmitted hydraulically to all parts before the oil has an opportunity to move at its free surface. It is therefore necessary either to reduce the intensity of the explosion or to

build the switch strong enough to withstand it. Since it becomes an expensive matter to build a switch to withstand a pressure of many hundreds of pounds per square inch the former alternative has received much attention. If the arc can be drawn out more quickly it follows that, other things being equal, extra resistance is introduced and the circuit is more quickly broken, thus cutting down the rate of heat generation and limiting the period during which it is being generated. Recent practice consequently tends towards quickening the break by decreasing the inertia of the moving parts and by accelerating their movement by means of powerful springs. Attempts have also been made to use the magnetic forces of the current for this purpose, since such an arrangement has the advantage that the more severe the short-circuit the greater is the speed of break. One of the most interesting suggestions in this connection is that of drawing out two arcs electrically in series, but arranged parallel close to each other in opposite directions, so that there is a repulsive effect between them proportional to the product of the currents in the two arcs, that is to say proportional to the square of the current. As the mass of the vapour carrying the current is so small the repulsive force will produce very rapid outward movement of the arcs in opposite directions, thus causing them to lengthen, which is in addition to and superimposed upon the lengthening due to the separation of the contacts.\*

Perhaps the most obvious way of reducing the violence of the explosion is to cut down the short-circuit current by reactance coils. Except in connection with generators the use of these coils is attended by many disadvantages, as pointed out in the discussions on the recent papers read before the Institution on this subject.† In any case it does not seem the correct procedure to use measures of a palliative nature at the present stage of switch design, since if there is one statement which can be made with more certainty than another it is that successful design has not reached its ultimate development. If used at all reactance coils should only be looked upon as an extra precaution kept in reserve to deal with unforeseen difficulties.

Switchgear is the most vital part of the system, because a fault on any part from the busbars to the far side of the switches is a busbar fault which will not only shut down the sub-station concerned but will also seriously derange the whole system, since even if it were possible automatically to isolate the particular sub-station all the "through" connections at the sub-station would be interrupted. In practice the only means of circumscribing the effects of a busbar fault are to divide the system into a large number of isolated networks, thereby involving uneconomical working, or to divide the system into sections by means of graded overload gear, which latter can seldom be relied upon to discriminate properly. It is accordingly imperative to make the switchgear a sound job, and any saving in capital expenditure is dearly bought if it in any way increases the risk of breakdown, particularly as the cost of switchgear is relatively small compared with that of the mains. One very common error is to save money

\* Hunter and Shand, British Patent No. 11,586 (1912).

† K. M. FAYE-HANSEN and J. S. PECK, "Current-limiting Reactances on Large Power Systems," *Journal I.E.E.*, vol. 52, p. 511, 1914. E. P. HOTLIUS, "Reactance and Reactance Coils in Power Circuits," *Ibid.*, vol. 52, p. 254, 1914. P. V. HUNTER, "Address as Chairman of the Newcastle Local Section," *Ibid.*, vol. 53, p. 102, 1915.

by proportioning switchgear according to the capacity of the apparatus which it controls; this entirely overlooks the primary duty of switchgear, namely, that of dealing with short-circuits, the severity of which may be as great on small apparatus as on large.

Faults on switchgear fall into three categories:—

- (1) Faults under short-circuit conditions.
- (2) Failure of apparatus under normal conditions.
- (3) Faults due to mistakes in operation.

(1) The means for preventing the failure of switches under short-circuit have already been considered, but if for any reason the switch is unable to operate properly an explosion may occur when breaking a short-circuit, and it is therefore desirable to limit the ensuing damage as far as possible by preventing the explosion affecting other panels, and by discharging any gases which may be produced in such a way that they do not cause short-circuits either on the damaged panel or on others. Even though a switch should explode it will often still interrupt the circuit, and it should therefore be isolated from other apparatus on the panel and all the leads to it should be insulated in order to prevent them being short-circuited by the products of the explosion. Other effects of a short-circuit, even on switchgear other than that immediately involved, are the large mechanical forces\* and the fusing of connections by the heavy currents. The latter effect is more particularly liable to occur in current-transformer primary windings, which should, therefore, always be of heavy section.

(2) Failure of apparatus under normal conditions may occur owing to such causes as plaster falling on busbars, and short-circuits due to mice, rats, etc., but such dangers can be readily guarded against once they are realized. Another fruitful cause of trouble is the potential transformer; these should not only be most carefully constructed but their number should be strictly limited, and under no circumstances should they be connected to the busbars without the intervention of an oil switch.

(3) Mistakes in operation probably account for more switchgear faults than any other cause and they are liable to be made even by the most careful operator, so that so-called "foolproof" arrangements should not be considered as disparaging to the operating staff and undoubtedly justify their slight extra expense, quite apart from the increased safety for operators and other persons who may be working on the switchgear.

The first and most obvious precaution is an interlock between each oil switch and its corresponding isolating switches, in order to prevent the isolating switches being either opened or closed unless the oil switch is open, thus preventing any possibility of making or breaking circuit on an isolating switch.

The second precaution is an arrangement to facilitate the routine earthing of feeders, which is responsible for numerous mistakes owing partly to the fact that the person who is carrying out the earthing cannot be at both ends of the feeder at once and has therefore to rely on a second party to see that the feeder is dead from the far end. By using permanent earthing switches it is a simple matter to interlock at the earthing end so as to ensure that the

earthing switches cannot be closed until the oil switch is opened, and vice versa; it is, however, difficult to protect against earthing a feeder which is alive from the far end, and all that can be done is to operate the earthing switches from a safe distance and to make the earth as quickly and definitely as possible.

The third and equally important precaution is to guard all live apparatus either by screens or by making the switchgear ironclad. Although it may sound difficult it is really a simple matter so to interlock the guarding arrangements with the switchgear mechanism that it is quite impossible to obtain access to live conductors or to make any such conductors alive while access can be obtained to them. Briefly, the guarding arrangements should fulfil the following conditions:—

- (a) That access cannot be obtained to the feeder ends unless they are earthed.
- (b) That access cannot be obtained to the oil switch unless it is isolated or earthed from both sides.
- (c) That access cannot be obtained to the busbars or gear in connection with them unless all the circuits connected to the particular section of busbars are isolated.

## II(b). THE ECONOMICAL SECTION OF MAINS.

Although it is generally known that the economical cross-section of a main is that at which the sum of the annual charges and the value of the energy lost is a minimum, it is seldom that any practical use is made of the formula. This is partly owing to the difficulty of calculating the losses and of placing the correct value upon them when calculated, and also partly because there is an impression that the resulting cross-section would work out to a figure inconsistent with that required by considerations of carrying-capacity and voltage-drop. In the following investigation an attempt is made to apply the formula to the special case of high-pressure distribution systems, and this seems to show that for this case at any rate the results are commercially useful.

The annual charges which have been taken for underground and overhead mains at various voltages are shown in Fig. 1. These are based on average commercial prices, allowing interest at the rate of 5 per cent per annum,<sup>\*</sup> and depreciation at 2 per cent for underground mains and 3 per cent for overhead mains, suitable allowance being made for trench work in the former case and for wayleave charges in the latter. With compound interest at 5 per cent the rates allowed for depreciation are sufficient to enable the underground mains to be replaced after  $22\frac{1}{2}$  years and the overhead mains after  $17\frac{1}{2}$  years, allowing a scrap value of 20 per cent in each case. It is probable that these figures considerably underestimate the life of mains, but conservative values have been taken so that there may be no question of the importance of capital charges being minimized†. It will be noticed that in the case of overhead mains only one curve is given, as up to 20,000 volts the

\* This is assumed to be a reasonable figure for a sound industrial concern operating on a fairly large scale; municipalities and similar bodies would usually be able to obtain their capital at a somewhat less rate of interest.

† No allowance is made for repairs, as these consist almost entirely of joining and labour, which are independent of the cross-section of the main.

\* These were discussed in Mr. P. V. Hunter's Address to the Newcastle Local Section, *Journal I.E.E.*, vol. 53, p. 102, 1915.

only difference is in the insulators, and this is so small that it is usually worth while to make the line suitable for 20,000 volts, although it may only be intended to operate it at a lower voltage. Higher voltages than 20,000 will not be considered, as the design and manufacture of apparatus for such higher voltages is not sufficiently standardized to enable definite annual charges to be assumed.

The only losses which are important enough to be taken into account in this investigation are the resistance losses in the copper conductors; and in estimating their value it is necessary, as in all estimates of the cost of producing electricity, to take account of the effect of the addition of the load considered to the normal load of the system. It is not the load factor of the particular type of load which matters, but its effect on the load factor of the system; in fact a load with quite a poor load factor may be distributed over the day in such a manner that it actually improves

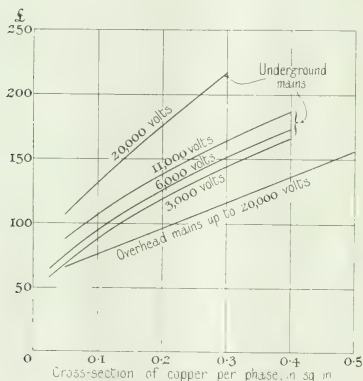


FIG. 1.—Annual Cost per Mile of Interest and Depreciation for Various Types of 3-phase Mains.

the load factor of the system considered as a whole. Unfortunately, resistance losses constitute a load which is far from beneficial; not only is there no diversity between the curve of losses and the main load curve, but the peaks of the former are accentuated owing to the fact that resistance losses vary as the square of the load. Of course the losses in different parts of the system will have different load factors, depending on the load factors of the currents in the particular parts, but considering them as a whole it is safe to assume that on the average the curve of total losses is proportional to the square of the main load curve.

In order to obtain definite figures as to the value of the energy lost, certain fundamental data must be assumed, and accordingly a system has been taken having a maximum load of not less than 50,000 kilowatts and an average load factor of 50 per cent; figures which fairly closely correspond to what may be expected if the system deals with the general demand over a reasonably extended area.

In Fig. 2 the full-line curve shows the assumed load curve of the typical system with a load factor of 50 per cent, and the dotted curve shows to an enlarged scale the shape of the corresponding loss curve, which has a load factor of only 35 per cent. From an analysis of the fixed and running charges the cost per unit of generating these

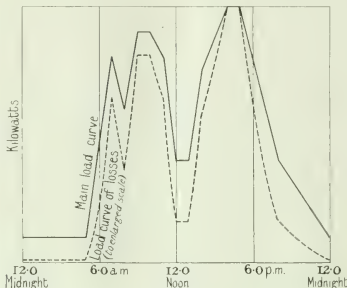


FIG. 2.—Load Curve of Typical System with 50 per cent Load Factor and Corresponding Curve of Losses (to Enlarged Scale) with a Load Factor of 35 per cent.

losses at the power stations can be calculated, and to this must be added the fixed charges on the increased capacity of the distribution system necessary to transmit these losses. They do not directly increase the carrying capacity of the distribution system since they are manifested as

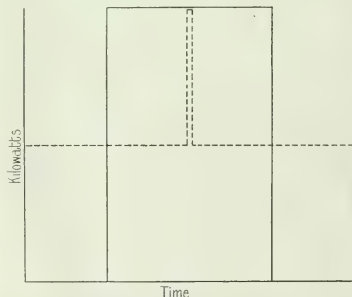


FIG. 3.—Extreme Forms of Load Curve for a given Number of Units at 50 per cent Load Factor.

voltage-drop, but this causes the load to be supplied at a lower voltage and thus incidentally increases the current that the distribution system has to carry. Since the power stations can seldom be located at the exact electrical centre of gravity of the load, the losses have to be transmitted, on the average, over say two-thirds of the distribution system and should therefore bear two-thirds of

the fixed charges of the latter. There are of course further losses in transmitting the primary losses, but these are quantities of the second order and may be neglected. Taking the cost of the distribution system at two-thirds that of the power stations, the value of resistance losses on the typical system considered is about 0.25d. per unit.

Since the resistance losses over a given time are proportional to the mean square of the current, it is very necessary in calculating them to take account of the shape of the current load-curve. This will be readily seen by considering the two extreme forms of a 50 per cent load-curve shown in Fig. 3. In the first case the R.M.S. current is equal to the average current, while in the second case it is  $\sqrt{2}$  times it for the particular load factor of 50 per cent; or more generally for any load factor it is  $\sqrt{(100 \div \text{load factor})}$  times the average current. The load curves which are met with in practice lie between these extremes, and for the typical 50 per cent load curve given in Fig. 2 the R.M.S. current is 1.18 times the average current. The full lines

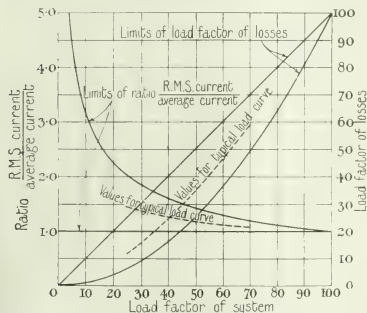


FIG. 4.—Effect of Shape of Load Curve on R.M.S. Current and Load Factor of Losses.

in Fig. 4 show the extreme values of this multiplier for different load factors, and the dotted line the approximate values for the usual type of load curve; corresponding extreme and usual values for the load factor of the losses are also indicated.

On the system which we are considering, the load factor of the mains nearest to the power stations will not be much less than the system load-factor, viz. 50 per cent, but for mains on the outskirts it will be much less, probably as low as 30 per cent. Over the whole network the average would probably be about 40 per cent, and it will be seen from Fig. 4 that the corresponding R.M.S. current would be 1.25 times the average current. Calculating the losses on this basis and taking their value as 0.25d. per unit, the annual value of the losses per mile of 3-phase main is  $\pounds 0.000296 \frac{1}{A}$ , where  $I$  is the maximum current in amperes and  $A$  is the cross-sectional area of the conductor of each phase in square inches. The value is expressed for convenience in terms of the maximum current, since mains are usually laid to suit a given maximum current.

By adding the curves of annual charges and value of losses for mains of various sizes for any particular maximum current, a curve is obtained of the type shown in Fig. 5, which refers to a 6,000-volt underground cable required to deal with a maximum current of 100 amperes. The most interesting feature of this curve is that the most economical section is not very definite; it is actually 0.09 square inch, but for  $2\frac{1}{2}$  per cent increase in the total annual costs the section can be increased 44.5 per cent, or decreased 27.2 per cent, the corresponding figures for 5 per cent increase in annual costs being 65.5 per cent and 36.1 per cent respectively. It follows that it is not sound practice to cut the section of mains too fine, more especially since it is a most expensive matter after a main is once laid to increase its carrying capacity if this should prove too small.

In order to see to what extent the results are dependent on the particular system load-factor which has been selected, a corresponding curve has been calculated in exactly the same way but assuming a system load factor of only 40 per cent. This is shown dotted in Fig. 5 and

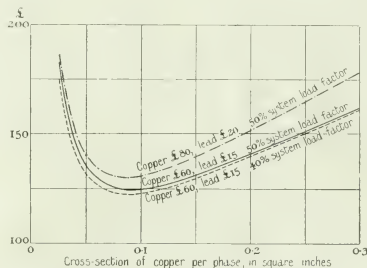


FIG. 5.—Combined Annual Cost of Interest, Depreciation, and Energy Losses per mile of 6,000-volt Underground Main carrying a Maximum Load of 100 Amperes.

gives a reduction of only 2 per cent in the most economical section and 2 per cent in the minimum total annual cost per mile, compared with the original curve. The difference between the two curves is so small because the reduction in the number of units lost at the lower load factor is nearly balanced by the extra value of the losses per unit due to the lower load factor of the losses. A further curve has also been added—shown chain dotted—to show the extent to which the results are affected by the price of copper and lead. The original curve corresponds to basis prices of  $\pounds 60$  and  $\pounds 15$  per ton respectively, while the chain-dotted curve corresponds to basis prices of  $\pounds 80$  and  $\pounds 20$  per ton. This shows that the influence of ordinary variations in metal prices is negligible.

By plotting a series of curves similar to the full-line curve in Fig. 5, the curves shown in Fig. 6 have been obtained. The full lines in Fig. 6 give, for underground and overhead mains at various voltages, the most economical cross-section for any given maximum current, while the dotted lines show the increased cross-section corresponding to 5 per cent extra annual cost. It will be

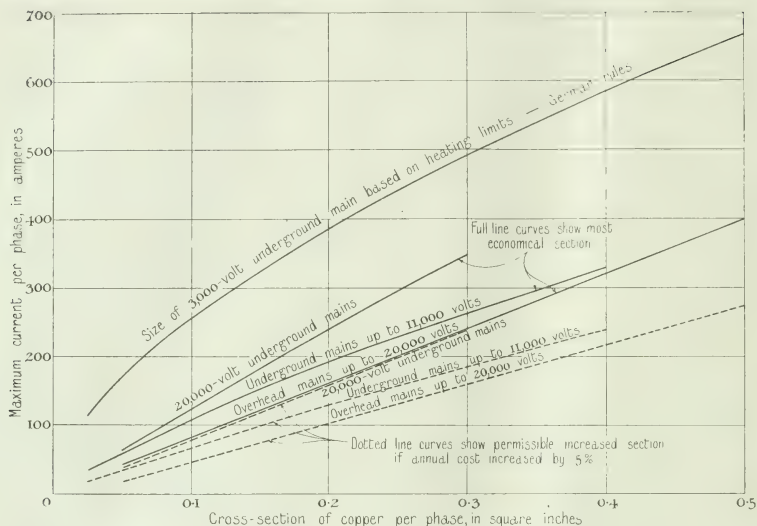


FIG. 6.—Most Economical Cross-sections of 3-phase Mains for Various Maximum Currents.

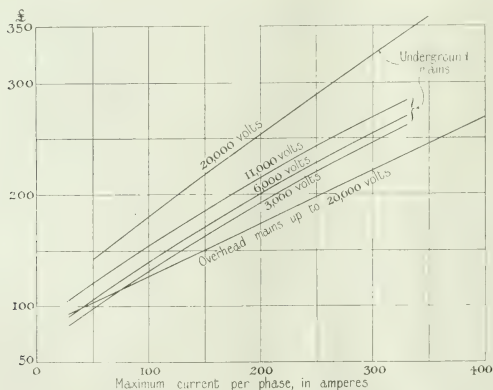


FIG. 7.—Minimum Total Annual Cost per Mile of 3-phase Mains for Various Maximum Currents.

noticed that up to 11,000 volts in the case of underground mains, and up to 20,000 volts in the case of overhead mains, the voltage makes no difference to the economical cross-section; and from Fig. 1 it will be seen that this is because between those limits the annual charges happen to differ by approximately constant quantities which are independent of the cross-section.

To show how the economical cross-sections compare with sections settled by considerations of the safe carrying-capacity, a further curve has been plotted showing the carrying-capacity of armoured 3-core 3,000-volt cable on the basis of the Rules of the Verband Deutscher Elektrotechniker.<sup>2</sup> As the Rules refer to continuous loads, and the maximum load is usually not maintained for a sufficient time to heat up the cable fully, the curve has been plotted on the assumption that the equivalent heating current is the mean between the R.M.S. current and the maximum current, i.e. 0.75 of the maximum current in the present instance with a 40 per cent feeder load-factor. The reduction for voltages up to 11,000 is not more than 10 per cent, but unfortunately no figures are available at present for 20,000-volt cables. It will be seen that except for 20,000-volt cables the economical section gives an overload margin of as much as 100 per cent in nearly all cases, and even for 20,000-volt cables it is evident that a considerable margin exists, so that it is quite permissible to settle the cross-section of mains on the basis of maximum economy. That it does not pay normally to operate cables at the maximum current density allowed by heating-limits is of interest, since it means reduced voltage-drop per mile and consequently an increased radius of distribution for a given voltage.

From the series of curves used in determining the economical sections it is also readily possible to find the minimum annual costs of interest charges, depreciation, and losses per mile of main for given maximum currents, on the assumption that the economical sections which correspond to those currents are used. If an allowance for repairs is added, the resulting figures will give the total minimum annual cost per mile of main, thus providing a definite basis on which the relative economy of alternative arrangements of mains can be determined. The curves in Fig. 7 have been obtained in this manner, the allowance for repairs being taken as a certain percentage of the cost of a 0.15 sq. in. main, since repairs consist almost entirely of jointing and labour and their cost is therefore independent of the cross-section. The percentages which have been taken are 1 per cent for underground mains and 2 per cent for overhead mains, but these must only be looked upon as approximations, since the cost of repairs depends on so many conditions.

#### II(b). THE LAY-OUT OF THE DISTRIBUTION SYSTEM.

Except in special circumstances it is usually essential for each sub-station to have at least two separate sources of supply, and, if the supply to the sub-station is not to be interrupted by a failure of one source, some form of discriminating protective device must be installed on each feeder in order to isolate it automatically in the event of its breakdown. It is, however, not so generally recognized that it is of equal importance that a fault on one feeder must not interfere with the supply through the sound

feeders however severe the fault may be. The only forms of protection in commercial use which meet these conditions under all circumstances are the balanced-current protective system with pilot wires and the split-conductor protective system. Both have the further advantage that the isolation of the faulty feeder is practically instantaneous and can be effected with quite a low value of the fault current so that the disturbance to the general system is a minimum. Full particulars of these protective systems and of their advantages are given in Mr. Wedmore's recent paper,<sup>3</sup> the split-conductor system being finally recommended as the more suitable for feeder protection.

It is probable that one or other of them would be universally used if it were not that there is often an impression that they involve extra capital cost which is not justified by the extra security they give. Undoubtedly they increase the cost per mile of a main of given section, but this is counterbalanced by the saving effected by the possibility of using an interconnected system which allows of:—

(a) A reduction in the cost of mains due to the saving in spare feeders.

(b) A reduction in the cost of mains due to the possibility of replacing a number of small feeders by a few large ones which are cheaper per ampere of carrying-capacity.

(c) A reduction in the amount of switchgear required.

(d) A reduction in the total annual cost of mains, owing to it being possible to take advantage of the diversity between the demands of different sub-stations.

The extent to which a system may be safely interconnected by the use of these devices is shown by Fig. 8, which illustrates diagrammatically the high-pressure distribution system on the North-East Coast. No less than 350 sub-stations are connected to this system, and it is fed by 15 power stations, many of which utilize waste energy in the form of exhaust steam and coke-oven gas. The whole of the feeders shown are normally in commission and interconnected, the older ones being equipped with balanced-current protection and the more recent ones with split-conductor protection. As showing the reliability of both these forms of protection the operating records of this system show that over a period of time, selected quite at random, faults occurred on 23 feeders equipped with automatic protection, and that in 22 cases the faulty feeder was instantaneously isolated without causing an interruption of supply to a single sub-station, except in one instance where the sub-station in question was given a non-duplicate supply through the faulty feeder. In the remaining case although the protective gear operated satisfactorily one of the feeder switches failed to open due to a mechanical fault; this was equivalent to a busbar fault and brought out the overload gear at two sectioning points, thus limiting the trouble to this section of the system.

In the following investigation an attempt is made to give definite figures for the saving effected by an interconnected system. These figures show that the saving is not only sufficient to balance the cost of the special protective devices, but that a system so equipped is actually cheaper than systems protected by less efficient methods which do not give the same freedom from interruption of supply.

\* E. B. WEDMORE, "Automatic Protective Switchgear for Alternating current Systems." *Journal I.E.E.*, vol. 53, p. 157, 1915.

<sup>2</sup> *Zeitschrift L.L.Z.*, vol. 52, p. 789, 1914.

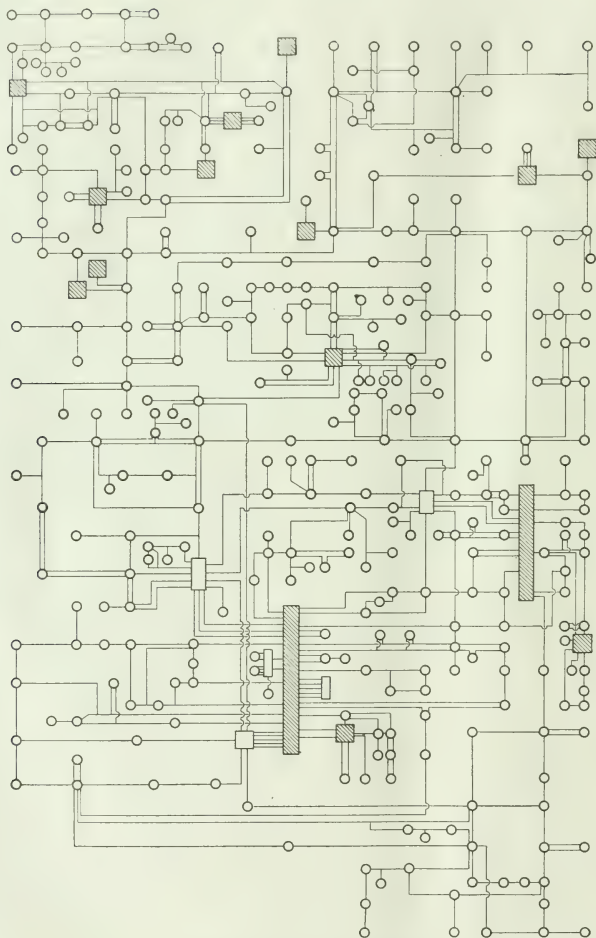


FIG. 8.—North-East Coast High-pressure Distribution System.

*Note.* Generating stations shown cross-hatched.

In order that the results may be on the conservative side the extra cost of the special protective devices has been taken at 10 per cent on the switchgear, including building accommodation, and at two shillings per yard on the mains, which is sufficient to cover the cost of balanced-current protection and decidedly more than sufficient to cover the cost of split-conductor protection. In the first place a comparison will be made between the three types of system that are available in the case of the supply to a number of sub-stations the supply to which must be reasonably free from interruption. These are :—

(1) An interconnected system equipped with balanced-current or split-conductor protection, which ensures complete continuity of supply to all sub-stations in the event of a fault on a feeder.

(2) A simple radial system with duplicate feeders direct from the power station to each sub-station, equipped with time-limit overloads at the power-station end and reverse-power relays at the sub-station end. This limits the risk of interruption to the sub-station fed by the faulty feeder and has been adopted for important supplies such as that to the London Underground Railways. Owing to the defects of the reverse-power relay it cannot ensure complete continuity of supply to the sub-station affected.

(3) A series radial system with duplicate feeders to each sub-station protected as in (2), but with direct feeders from the power station to only half the sub-stations, each of these in turn feeding one of the remaining sub-stations. This involves graded overload gear, and a faulty feeder may shut down both the sub-stations in connection with it and will probably shut down one of them; it is therefore only permissible where continuity of supply is not of such vital importance.

For the purpose of the comparison a typical case is assumed of an area of 25 square miles with the power station at the centre and a sub-station with a maximum load of 500 kilowatts at 0.8 power factor and a load factor of 30 per cent situated at the centre of each square mile, the distribution being effected by underground mains at 6,000 volts. It is assumed that owing to the diversity between the various sub-station loads the power-station load-factor will be 50 per cent, and the average feeder load-factor on an interconnected system 40 per cent. The average maximum feeder currents are therefore deduced by assuming the sub-station maximum demand to be reduced in the ratio of the sub-station load-factor to the average feeder load-factor. This only holds for the interconnected system, but in the first instance the same reduced sub-station demands will be taken for other types of system, *i.e.* the advantage which an interconnected system gains from its utilization of diversity is neglected.

The annual cost per switch panel is taken from Fig. 12, and the annual cost of the mains from Fig. 7, the proper deductions being made in the case of types (2) and (3) for the omission of the special protective devices. Table 1 gives the comparison, while the diagrammatic lay-outs of the three types of system are shown in Fig. 9 (a), (b), and (c).

In certain cases where momentary interruption of supply is not of great importance a "tee" system has been used, arranged as shown in Fig. 9 (d). Each sub-station is normally given a non-duplicate supply from one of the feeders, and arrangements are made for the sub-station to be changed over to the other feeder in emergency, thus

involving a complete temporary interruption in the supply to all the sub-stations fed by the faulty feeder. In a modification of this system both tees into the sub-station are normally closed through switches equipped with time-limit gear, but the sub-station busbars are sectioned by a special switch. The sectioning switch may be either left open or it may be closed and equipped with instantaneous overload gear so that it will immediately trip in case of a feeder fault. In either case supply is automatically maintained to half the sub-station busbars, and by opening the faulty feeder switch and closing the sectioning switch complete supply to the sub-station can be resumed.

Table 2 gives a comparison of these systems with the interconnected system, and it is interesting to note that the latter is still cheaper in spite of the great sacrifices in security entailed by the "tee" systems.

The foregoing comparison proves that the interconnected system is the most economical for the particular case which has been selected as typical; but in order to make the investigation complete it is necessary to show that this superiority still holds under other conditions, and accordingly the interconnected system will be compared with the cheapest system giving reasonable security of supply—the series radial system—under various modified conditions which may obtain in practice. These are :—

(1) The same number of sub-stations distributed one mile apart in a ring round the power station, or in line one mile apart with the power station at the centre, as shown in Fig. 9 (e), (f), (g), and (h).

(2) The area of supply extended or decreased with the same number of sub-stations and the same total load on the system, *i.e.* the sub-stations situated at the increased and decreased spacings of one per 4 square miles and four per square mile respectively, instead of one per square mile, the load per sub-station remaining the same.

(3) The area of supply extended to, say, 49 square miles with the same density of load and a correspondingly increased number of sub-stations supplied from the central power station, as shown in Fig. 9 (i) and (j). A further extension of the area of supply to 81 square miles has also been worked out, but it has not been considered necessary to complicate Fig. 9 with details of this, as the lay-outs are similar to those for the 49 square miles. There is no need to consider a reduction in the area of supply as this is already quite small.

(4) The original distribution of sub-stations but with increased or reduced loads per sub-station, the alternative loads considered being 250, 1,000, and 2,000 kilowatts. The arrangement of feeders remains the same for the series radial system, as a cable capable of dealing with the load of two 2,000-kilowatt sub-stations in emergency is not too large to be handled. For the interconnected system it is necessary to run more feeders from the power station to deal with the heavier loads, the feeder arrangements which would be adopted for the 1,000- and 2,000-kilowatt sub-stations being shown in Fig. 9 (k) and (l) respectively.

The details of the comparison are given in Table 3.

The outstanding features of this comparison are :—

(a) The economy of the interconnected system is generally maintained.

(b) The saving effected by an interconnected system rapidly increases as the area of supply is enlarged. This

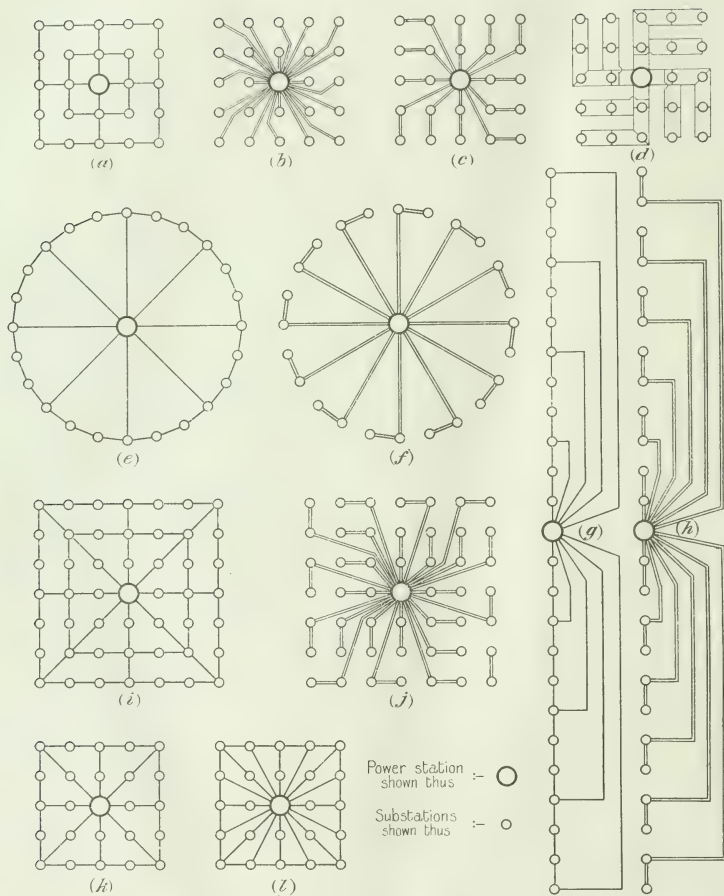


FIG. 9.—Diagrammatic Lay-outs of Distribution Systems.

is important as only relatively restricted areas have been considered.

(c) The saving is greatest for lightly loaded sub-stations and decreases as the sub-station loading increases. In the

to diversity has been ignored, and secondly it will be found on investigation that a point has been reached at which distribution at so low a voltage as 6,000 is uneconomical. The question of the most economical distribu-

TABLE 1.

Type of System	Reference to Figs.	No. of Switches	Mileage of Mains	Annual Costs, £	Percentage Increased Cost over Interconnected System
Interconnected ... ..	9 (a)	64	32.0	4,752	—
Simple radial ... ..	9 (c)	96	93.7	7,664	61.3
Series radial ... ..	9 (c)	96	61.2	6,075	27.3

TABLE 2.

Type of System	Reference to Figs.	No. of Switches	Mileage of Mains	Annual Costs, £	Percentage Increased Cost over Interconnected System
Interconnected ... ..	9 (d)	64	32.0	4,752	—
Semi-duplicate "tee" ... ..	9 (d)	80	48.0	5,478	15.3
Change-over "tee" ... ..	9 (d)	50	48.0	5,016	9.8

TABLE 3.

Nature of Modification to the Typical System	Type of System	Reference to Figs.	No. of Switches	Mileage of Mains	Annual Cost, £	Percentage Increased Cost over Corresponding Interconnected System
Sub-stations distributed in ring	Interconnected	(a)	64	54.0	8,179	—
	Series radial	(c)	96	115.0	19,977	34.2
Sub-stations distributed in line	Interconnected	(a)	66	84	11,508	—
	Series radial	(c)	96	168	15,644	35.0
Sub-stations spaced one per 4 square miles	Interconnected	(a)	64	64.0	8,736	—
	Series radial	(c)	96	122.4	11,103	27.1
Sub-stations spaced four per square mile	Interconnected	(a)	64	16.0	2,760	—
	Series radial	(c)	96	30.6	3,502	20.0
Area of supply increased to 40 square miles	Interconnected	(a)	128	60.0	11,108	—
	Series radial	(c)	192	166.0	16,135	45.2
Area of supply increased to 81 square miles	Interconnected	—	192	120.8	20,521	—
	Series radial	—	320	347.7	35,424	61.4
Sub-station load reduced to 250 kilowatts	Interconnected	(a)	64	32.0	3,060	—
	Series radial	(c)	96	61.2	5,295	33.7
Sub-station load increased to 1,000 kilowatts	Interconnected	(b)	64	35.3	6,533	—
	Series radial	(c)	96	61.2	7,721	18.2
Sub-station load increased to 2,000 kilowatts	Interconnected	(b)	80	53.2	10,460	—
	Series radial	(c)	96	61.2	10,572	1.0

case of the most heavily loaded sub-station it would appear at a first glance that while the interconnected system may have other advantages its direct economy is very small. This is only apparent, for in the first case the saving due

to diversity will be considered further at a later stage, but it may be noted now that with a sub-station loading as high as 2,000 kilowatts the distribution system costs 37.1 per cent more at 6,000 volts than it would at 11,000 volts,

while if a pressure of 11,000 volts were adopted the interconnected system would show a saving of 21·8 per cent compared with a series radial system at the same voltage.

The possible further savings which may be effected if diversity is taken into account have been considered, and without going into details of the calculation it may be taken as adding something of the order of  $4\frac{1}{2}$  per cent to the cost of a simple radial system, and rather less to the cost of a series radial system.

When comparing an interconnected system with other types, two further points must also be borne in mind.

(1) It is a very difficult matter exactly to forecast sub-station maximum loads or, as in the case of railways, definitely to fix the allocation between the various sub-stations. If the sub-stations are fed independently it is obvious that in proportioning the feeders to them allowance must be made for the assumed maximum loads being exceeded or varied, while if the sub-stations are intercon-

(a) The higher the voltage the less is the proportionate cost of the protective devices, which is practically independent of the voltage.

(b) The higher the voltage the smaller is the section of the mains for given loads, and consequently the greater the advantage offered by interconnection in reducing the total length of mains and increasing their average capacity.

This is shown very clearly by Table 4, which gives the comparison at various distribution voltages between the annual costs of interconnected and series radial systems for the typical distribution of sub-stations and a load of 2,000 kilowatts per sub-station.

#### II(c). THE MOST SUITABLE DISTRIBUTION VOLTAGE.

In setting the distribution voltage the primary consideration is that it shall be sufficiently high to ensure that the voltage variation at the boundaries of the supply area can be kept within a reasonable amount without

TABLE 4.

Distribution Voltage	Interconnected System		Series-radial System		Percentage Increased Cost of Series Radial System over Corresponding Interconnected System
	Reference to Fig. 9	Annual Cost, £	Reference to Fig. 9	Annual Cost, £	
6,000	(h)	10,469	(c)	10,572	1·0
11,000	(k)	7,634	(c)	9,295	21·8
20,000	(d)	7,084	(c)	10,756	34·8

TABLE 5.

Type of Main	Amperes per Square Inch at Maximum Load		Resistance Voltage-drop between Phases per Mile at Maximum Load	
	With the Economical Loading	With Decreased Loading Corresponding to 5 per cent Extra Cost	With the Economical Loading	With Decreased Loading Corresponding to 5 per cent Extra Cost
Underground mains up to 11,000 volts ...	910	635	68·1	47·5
20,000-volt underground mains ...	1,190	800	88·8	59·9
Overhead mains up to 20,000 volts ...	800	540	59·9	40·4

nected the particular distribution between the sub-stations does not greatly matter so long as the total system load is unaltered.

(2) The greater part of the saving effected by an interconnected system is in the trunk feeders, and in consequence it is more marked the farther the power stations are removed from the centres of load. In the above comparisons the power station has been taken at the electrical centre of gravity of the load and therefore at the least favourable position for the interconnected system.

So far the investigation has been limited to the comparatively low voltage of 6,000; but, speaking generally, the higher the system voltage the greater is the economy to be obtained by interconnection. This is obvious if it is remembered that—

putting an excessive amount of copper in the feeders. It is usually desirable that the voltage variation should not exceed 5 per cent either side of the normal, i.e. a total of 10 per cent, and from this about  $2\frac{1}{2}$  per cent should be deducted for transformer voltage-drop, leaving a permissible maximum drop of  $7\frac{1}{2}$  per cent in the high-pressure mains. Fig. 6 shows that under the same conditions the current density in the mains, and therefore the resistance voltage-drop per mile, is approximately independent of their section. The actual figures taken from Fig. 6 are given in Table 5.

As the power factor of most distribution systems is less than unity it is also necessary to take account of the inductive voltage-drop. This is not independent of the section, but given the current density from Table 5 and

the frequency of the system it can be readily calculated from the size and spacing of the conductors. Fig. 10 shows, for several typical sizes of both underground and overhead mains at various voltages, the relative amount by which the inductive drop increases the total voltage-drop at various power factors. The calculations are based on a frequency of 50 cycles per second and on a constant current density, since the economical value for the latter is independent of the power factor. They also assume the use of ordinary 3-conductor mains; if arranged for split-conductor protection the inductive drop would be appreciably reduced.

It is evident that the maximum radius of distribution and area of supply at a given voltage will vary according to the power factor of the system and to the various factors which determine the inductive drop, but in order to give

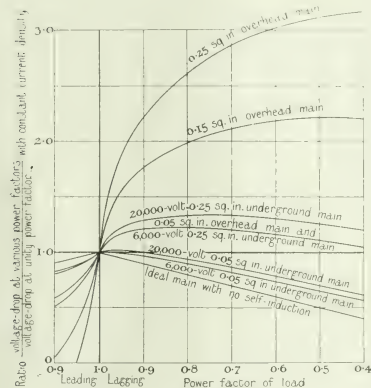


FIG. 10.—Effect of Inductive Drop at Different Power Factors for Various Mains.

an approximate idea of the relative figures for the maximum radius and area at various voltages the curves given in Fig. 11 have been prepared on the following assumptions:—

- (1) Permissible voltage-drop 7.5 per cent.
- (2) Average power factor 0.8.
- (3) A network comprising equal lengths of underground and overhead mains.
- (4) An average cross-section of main of 0.15 square inch.
- (5) A frequency of 50.

It is interesting to note that, although it is more economical to run higher voltage cable at an increased current density, the curves of both area and radius have still a steep upward tendency at 20,000 volts. This would be further accentuated if allowance were made for the fact that the average cross-section of main tends to decrease at higher voltages, with a corresponding decrease

in the value of the inductive drop relative to the resistance drop.

It is, however, not sufficient to settle the distribution voltage on the basis of permissible voltage-drop alone. It

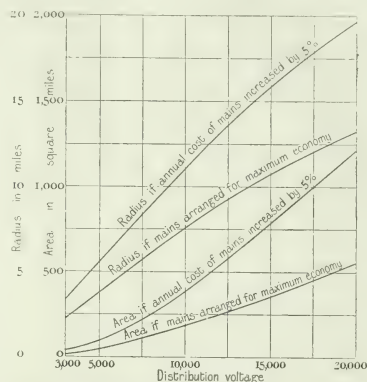


FIG. 11.—Radius and Area of Distribution at Various Voltages.

Permissible drop 7.5 per cent  
Frequency 50 s  
Average power factor 0.8  
Equal lengths of underground and overhead mains

is also important to choose that voltage which gives the cheapest distribution system, and from this point of view it may often pay to use a voltage much higher than that which is required by the conditions of voltage-drop.

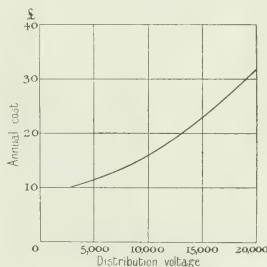


FIG. 12.—Annual Cost of Switchgear per Panel.

Generally speaking, the higher the loads which have to be dealt with the higher is the economical voltage; but it is also necessary to take into consideration the proportion between the total number of switches required and the total mileage of mains, as the cost of switchgear increases with the voltage. Fig. 12 gives fairly safe

figures for the annual cost per switch at different voltages on the basis of annual charges of 8 per cent on the switchgear and the corresponding building accommodation, and these figures have been used in the following investigation.

Taking a system comprising 24 sub-stations evenly spaced as in Fig. 9 (a), and allowing an average of 24 switches per sub-station for controlling the step-down transformers, the total annual cost of switchgear and mains has been calculated for various distribution voltages and various sub-station loadings. In addition the spacing of the sub-stations has also been varied so as to give several comparative proportions between the number of switches and the mileage of mains. From these results the series of curves given in Fig. 13a have been plotted showing the most economical voltage under the varying conditions.

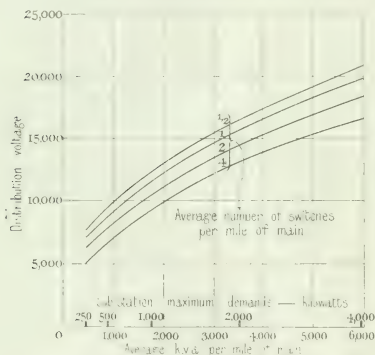


FIG. 13a.—Economical Distribution Voltage.

It will be seen by reference to Fig. 7 that the annual costs of mains of varying sections lie approximately on straight lines, and it is therefore permissible, by plotting the curves in Fig. 13a to a base of average demands, to make the results applicable to any arrangement of network whatever its type or extent. In order to find the most economical voltage for a given distribution of loads, the procedure would then be to assume a voltage which it is anticipated will be about correct, to lay out the distribution system on this basis, calculate from this the average number of kilovolt-amperes per mile of main and the number of switches per mile of main, and then from these two figures find from the curves in Fig. 13a what the most economical voltage would be. If the original voltage which had been assumed should prove to have been so incorrect that the arrangement of feeders and the number of switches would be appreciably altered by the adoption of the revised voltage, it may be desirable to lay out the system afresh with the revised voltage and afterwards check the results again with the curves in Fig. 13a, the method being thus one of trial and error. As a rule,

however, the first voltage assumed should be sufficiently close to the correct figure to enable the latter to be obtained by the first trial. The economical voltage obtained in this way must of course be always checked to ensure that it also meets the requirements of voltage-drop.

In order to give some idea of the extent to which the economical voltage can be departed from, the curves given in Fig. 13b have also been calculated; these show the upper and lower limits of voltage corresponding to an increase of 5 per cent in the cost of the distribution system. The limits are fairly wide, but, if they are exceeded, the extra cost of the distribution system increases at a cumulatively rapid rate. In practice it is advisable to adopt a voltage in the neighbourhood of the upper limit in order to keep down the voltage-drop as much as possible, and also in order to make allowance

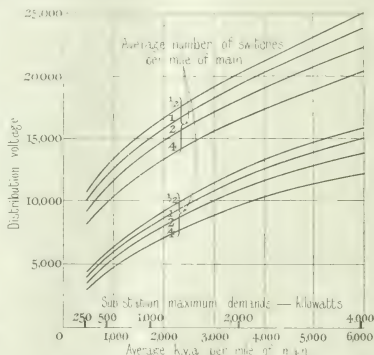


FIG. 13b.—Upper and Lower Limits of Distribution Voltage for 5 per cent increased Cost of Distribution System.

for the increase in the density of load which will usually occur.

As might be expected, Fig. 13 shows that the heavier the loads to be supplied and the more they are concentrated the higher is the most economical voltage. It should be noticed that the curves show no signs that at 20,000 volts the maximum economical voltage has been reached, provided the system loading is heavy enough, and hence for the larger systems of the future we may expect that for economical reasons alone the distribution voltage will be raised above 20,000 volts.

These calculations only refer to underground mains; with overhead mains the economical voltage will be higher, since there is so little difference between their cost at various voltages.

In order to see what are typical figures in actual practice for the number of switches per mile of main and the average number of kilovolt-amperes per mile of main, the following table has been prepared for two typical systems for which the author has had access to the necessary data, and as a matter of interest the corresponding economical

and limiting values for the distribution voltage have been deduced from Fig. 13.

TABLE 6.

System voltage actually adopted ...	5,500	20,000
Number of switches per mile of main ... ..	2.63	0.725
Average maximum kilovolt-amperes per mile of main ... ..	450	3,500
Most economical system voltage ...	5,700	16,000
Upper and lower limits for system voltages with 5 per cent extra cost of distribution system	9,500 3,200	20,000 12,000

## CONCLUSION.

So many factors are involved that it has only been possible to attempt a general survey of the problem of high-pressure distribution, but it is hoped that this may prove useful as a starting-point in the detailed consideration of any particular case.

Theoretical calculations must, however, be used with caution. The results of the graph and the slide rule should always be considered in conjunction with the results of practical experience and the whole sifted by the exercise of judgment, accuracy in which is the true test of an engineer. The following paragraph in Professor Arthur Schuster's address to the British Association is so pertinent

to the subject that perhaps its quotation may be permitted:—

"Why does a theory ever fail, though it may be sound in reasoning? It can only do so because every problem involves a much larger number of conditions than those which the investigator can take into account. He therefore rejects those which he believes to be un-essential, and if his judgment is at fault he goes wrong. But the practical man will often fail for the same reason. When not supported by theoretical knowledge he generalizes the result of an observation or experiment, applying it to cases where the result is determined by an altogether different set of conditions. To be infallible the theorist would have to take account of an infinite number of circumstances and his calculations would become unmanageable, while the experimenter would have to perform an infinite number of experiments, and both would only be able to draw correct conclusions after an infinite lapse of time. They have to trust their intuition in selecting what can be omitted with impunity, and if they fail, it is mainly due to the same defect of judgment. And so it is in all professions: failure results from the omission of essential considerations which change the venue of the problem."

In conclusion the author wishes to record his obligations to the Newcastle-upon-Tyne Electric Supply Company, Ltd., and associated power companies on the North-East Coast, and to their consulting engineers, Messrs. Merz and McLellan, for permission to use much of the data on which the conclusions of the paper are based.

## THE MATHEMATICAL DESIGN OF TRANSFORMERS.

By Professor DAVID ROBERTSON, D.Sc., Member.

*(Paper first received 3 August, and in final form 10 November, 1915.)*

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## 1. INTRODUCTION.

Since the publication in the beginning of 1911 of the author's method of getting the leading dimensions of a transformer\* the conviction has grown on him that the essential points of his theory were obscured in the original paper by the mass of detail included in it. The criticisms recently published by Mr. A. R. Low† confirm the impression that the time is now ripe for a restatement of the method, with such slight modifications as have been found desirable.

## 2. DATA REQUIRED.

The data generally specified for a transformer in addition to its output are:—Temperature rise; efficiency, or iron and copper losses; voltage-drop; and exciting current. These are not, however, independent of one another. In particular, temperature rise and efficiency are very closely related, the standard commercial efficiencies being the lowest ones at which the temperature rise can be kept within the specified limits with the given output, type of transformer, and method of cooling.

\* BOYLE and ROBERTSON. "A Treatise on Transformers," chap. 10.  
 † A. R. LOW. "Dimensions of Transformers." *Journal I.E.E.*, vol. 57, p. 512, 1915.

With given dimensions, the relation between the losses and the load is perfectly definite, but the heating depends very much on the method of cooling, on the size and shape of the tank, and on the skill of the designer in arranging the ducting. The voltage-drop at unity power factor is practically determined by the copper loss, while the exciting current largely depends upon whether the iron loss is a high one or a low one for the other ratings. Owing to the variation of the permeability of the iron, no useful algebraic relations can be obtained between the exciting current and the dimensions.

Although it is quite easy to obtain a relation between the temperature rise and the "fundamental length," owing to the uncertainty of the thermal constants it is best to take the losses as the basis of the design. If these are normal for the output, type, and materials, the others will also be normal.

For the purposes of this theory, the transformer is supposed to consist of copper and iron spaces, each of which entirely fills the opening through the other. The boundary between them is drawn apparently arbitrarily, but it is in reality fixed by the assumptions made when estimating the mean length of one turn, and it is conveniently taken as the circle or rectangle circumscribing the iron core. We must suppose that the space-factors, as given by the ratio of the net section of the metal to the cross-sections of these spaces, can be estimated beforehand with sufficient accuracy. If in the final design the clearances do not come out quite right, it will usually be sufficient to adjust the window to suit. It is only when the change of proportions thereby introduced is considerable that a fresh estimate and design need be made.

In addition, we must know the properties of the materials employed, and, if the cheapest arrangement is required, also their relative cost, including labour.

## 3. ASSUMPTIONS.

Since it is impossible to take complete account of all the variables in a general theory, certain assumptions are necessary to bring the problem within the compass of our mathematical knowledge. Those made in this theory are:—

- (1) The flux density is uniform throughout the iron.
- (2) The current density is uniform throughout the copper.
- (3) The cost of active material may be divided into two parts, of which one is proportional to the amount of iron and the other to the amount of copper.
- (4) The copper loss is proportional to the square of the current density.
- (5) The iron loss is proportional to the square of the flux density.

The last three assumptions do not arise until we seek to obtain the best proportions for given conditions, such as

minimum cost, or until we compare different types with one another. They scarcely affect the problem of designing to given proportions.

None of these assumptions is strictly accurate. The first would require the corners of the cores to be rounded off, which is not usually done, as the cost of doing so would exceed the value of the scrap metal removed. It also excludes the well-known possibility of reducing the cost by diminishing the section of the wound cores while increasing that of the unwound yokes, but in any case the extent to which this could be practically applied is limited by excessive exciting current and local heating.

The second assumption is open to the criticism that the minimum loss with a given volume of copper is not obtained

weights about  $2\frac{1}{2}$  per cent less. The effect on the most favourable proportions is quite negligible, but it is such as to make long thin coils appear a trifle better than they really are. This matter is more fully dealt with in Appendix 3.

The third assumption is probably as nearly accurate as any generalization regarding cost can be. When making comparisons between different types it should be remembered that it neglects differences between the labour of winding equal amounts of copper in round or rectangular coils, in short thick coils or in long thin ones, with thin wire or with copper bar, of preparing stampings of different shapes, and of assembling different types. It also leaves out differences in the proportional cost of material cut to waste.

The fourth assumption calls for no special comment, but the fifth is the weakest of them all. So far as the eddy-current component is concerned it is accurate enough, but it is not quite true for the hysteresis component. However, except at flux densities below 10,000 lines per square centimetre, its variation from the truth is of no importance, as may be seen from the loss-length curves of Fig. 1.<sup>10</sup> It drops less than 2 per cent when the flux density is raised from 10 to 20 kilolines per square centimetre, but rises about 13 per cent when it is reduced to 5 kilolines per square centimetre.

#### 4. SYMBOLS.

In the mathematical work the following symbols are employed:—

$\Sigma IE$  = Aggregate loading of all the windings.

$P_i, P_c$  = Iron and copper losses.

$f$  = Frequency of supply.

$f$  = Form-factor of the E.M.F. wave.

$E_1, E_2$  = Primary and secondary electromotive forces.

$\equiv$  = Primary and secondary potential differences.

$I_1, I_2$  = Primary and secondary currents.

$I'$  = R.M.S. current density (supposed uniform).

$B_m$  = Maximum flux density (supposed uniform).

$\rho_c$  = Copper-loss coefficient (resistivity).

$= P_c \div (I')^2 V_c$ .

$K_i$  = Iron-loss coefficient  $= P_i \div B_m^2 V_i$ .

$L_0$  = Fundamental length  $= (S_{1S} S_{cS} \div L_1 L_c)^{\frac{1}{2}}$ .

$L_L$  = Loss-length  $= (K_i \rho_c)^{\frac{1}{2}} \div 4 f$ .

$L_1, L_c$  = Equivalent mean lengths of iron and copper such that  $L_1 S_1 = V_1$ , and  $L_c S_c = V_c$ .

$L_{1S}$  = Depth of iron space perpendicular to laminations with rectangular coils.

$L_{cS}$  = Distance between yokes.

$I_{1S}$  = Width of iron space.

$I_{cS}$  = Conventional winding depth round each wound limb = width of opening through iron, or half of it according to type.

$S_{1S}, S_{cS}$  = Cross-sections of iron and copper spaces.

$S_1$  = Net cross-section of iron  $= a_1 S_{1S}$ .

$S_c$  = Net cross-section of copper  $= a_c S_{cS}$ .

$S_{w1}, S_{w2}$  = Cross-section of primary and secondary wire.

$V_0$  = Fundamental volume  $= L_0^3$ .

$V_i, V_c$  = Net volumes of iron and copper.

\* The effects of the departure of the facts from our assumptions are discussed in an article by W. E. BURNAND on "Loss and Efficiency of Transformers" in the *Electrician*, vol. 75, p. 10, 1915.

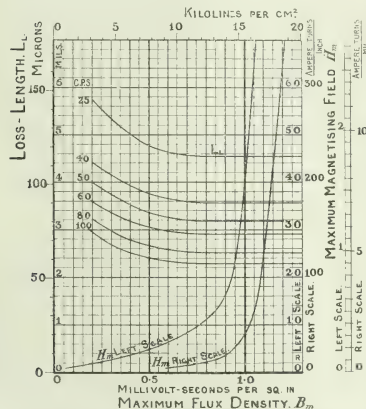


FIG. 1.—Loss-Length and Magnetizing Field for Sankey's "Stalloy" Iron 20 mils. thick. (The resistivity of copper is taken at 0.90 microhm-inch.)

in every case with equal current densities in the primary and secondary coils owing to differences in their mean perimeters.

With a given copper space, the minimum copper loss is obtained when the current density is so graded that it diminishes outwards in such a way as to make the resistance electromotive force the same for every turn. It is scarcely practicable to change the size of conductor from layer to layer, but with concentric coils we can give the outer coil more, and the inner coil less, than its fair share of the total section of copper.

With rectangular coils of standard proportions the outermost turn will be about 65 per cent longer than the innermost. Compared with uniform current density throughout, the copper losses will be about  $1\frac{1}{2}$  per cent less if the outer coil gets 50 per cent and the inner coil 44 per cent of the total section of copper. The result is thus the same as if the resistivity had been reduced  $1\frac{1}{2}$  per cent, making the loss-length about  $\frac{3}{4}$  per cent and the

$$M_I, M_C = \text{Mass of iron and copper.}$$

$\sigma_i, \sigma_c$  = Gross space-factors of the iron and copper spaces.

$$t = L_0 \cup L_1.$$
$$v = 1_{\mathbb{C}} \otimes 1_{\mathbb{C}}.$$
$$c = L_{\mathcal{L}}(s, 1)_{\mathcal{L}}$$

$a, b, c, \dots$  = Numerical coefficients, the meaning of which appears in the text.

$N_1, N_2$  = Number of turns in primary and secondary windings.

$\pounds$  = Cost of active material, including labour.

$$L_0 = \text{Fundamental cost} = c_{I\tau} V_0 = \text{cost of funda-}$$

mental volume filled with iron having same space-  
factor as iron space.

$C_I, C_C$  = Cost per unit volume of iron and copper.

$$m = \text{Specific cost ratio} = \frac{C_c \sigma_c}{C_i \sigma_i}$$

$$= \frac{\text{cost of copper space}}{\text{cost of same gross volume of iron space}}$$

## 5. DIMENSIONS AND EFFICIENCY.

The activity of the material is not changed if we suppose the copper fused into a single turn surrounding the magnetic circuit. We thus see that the aggregate volt-ampereage of all the windings is

[illegible]

$$= 4/f \left( \frac{P_1}{K_1 V_1} \right)^2 S_1 \left( \frac{P_1}{\rho_C V_C} \right)^2 S_C$$

since  $P_1 = K_1 B^2 V_1$  and  $P_C = \rho_C (I')^2 V_C$  . (2)

$$= f \frac{\sqrt{(P_1/P_c)} (S_1/S_c)^{1/2}}{\sqrt{(K_1/\mu_c)} (L_1/L_c)^{1/2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$= \sqrt{(P_1 P_2)} \sqrt{(\sigma_1 \sigma_2)} \left( \frac{S_1}{\sigma_1}, \frac{S_2}{\sigma_2} \div L_1 L_2 \right) \div \left[ \sqrt{(K_1 \rho_c)} \right] \quad (4)$$

$$= \sqrt{(P_i P_c)} \sqrt{(\sigma_i \sigma_c)} \left[ \left( \frac{S_i \times S_c}{L_i L_c} \right)^{\frac{1}{2}} \right] \div \left[ \sqrt{(K_i \rho_c)} \right] \quad (5)$$

The two expressions within square brackets are each of the nature of a length. The first depends on the dimensions of the transformer and is conveniently called the "fundamental length," while the other is a quantity depending on the loss-coefficients of the materials and may therefore be termed the "loss-length." The ratio between them is fixed by the output, losses, and space-factors. The loss-length would be constant for a given frequency and materials if our fifth assumption were exactly true. From Fig. 1, which gives values for 20 mils Stalloy calculated from the makers' curves and taking the resistivity of

copper at 0.90 microhm-inch (the steady current value at about 100° C., which leaves a margin at lower temperatures for the skin effect with alternating current), it will be seen that it actually is very constant except at low flux densities. For this material we may take the loss-length as follows:—

Frequency—

Cycles per sec.	...	25	40	50	60	80	100
Loss-length—							
Mils ...	...	4.7	3.7	3.3	3.0	2.6	2.4
Microns ( $10^{-3}$ mm.)		120	94	84	76	66	60

These values are correct for a flux density of 0.55 m.v.s. per sq. in. (8,500 lines per sq. cm.). Should the flux density come out lower than this, the iron losses will be somewhat greater than those assumed; whereas if the flux density be higher they will be slightly less. We should therefore take rather larger values of the loss-length if a low flux density is expected owing to the iron losses being small.

With graded concentric coils the loss-length should be taken 0.7 per cent lower than the standard, and the resistivity in the winding equations (29)–(31) as 1.37 per cent less than that assumed in calculating the loss-length.

## Putting

$$L_0 = \begin{pmatrix} S_I & S_C \\ L_I & L_C \end{pmatrix} = \begin{pmatrix} S_I & S_C \\ \sigma_I & \sigma_C \end{pmatrix} \begin{pmatrix} S_I & S_C \\ L_I & L_C \end{pmatrix}, \text{ the fundamental length } (6)$$

and  $L_L = \frac{\sqrt{(K_I \rho c)}}{4f}$ , the loss-length . . . . (7)

we get  $\Sigma I E = \sqrt{|P_1 P_C|} \sqrt{|\sigma_1 \sigma_C|} \cdot L_{xy}/L_1 \dots \dots \dots$  (8)

$$\text{or} \quad L_0 = \frac{\sum I E}{\sqrt{(P_1 P_2)} \sqrt{(\sigma_1 \sigma_2)}} L_L \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Thus, the fundamental length can be at once determined from the known data. Each of the leading dimensions is obtained by multiplying it by the proper factor, conveniently termed the "dimension coefficient," which depends on the type of transformer and on the proportions, being fixed when these are fixed, and so can be calculated once for all.

## 6. DIMENSION COEFFICIENTS.

If we write  $a, b, c, d, e$  for certain numbers easily obtained for any given type from a diagram,\* we can express all the dimensions in terms of one, say the width of the iron space, and the proportions which the others bear to that one. We are then able to get the values of the dimension coefficients and other functions required to carry the theory further. Thus:—

### Rectangular Coils.

$$L_1 = a L_{1s} + b l_{1s} + c l_{1s} = (a \gamma + b \gamma + c) l_{1s}, \dots, L_4 = a L_{4s} + b l_{4s} + c l_{4s} = (a \gamma + b \gamma + c) l_{4s}, \dots, \quad (10)$$

$$L_C = c I_{CS} + z I_{CS} + z I_{CS} = (c + z + z) I_{CS} = \pi (I_{CS} + I_{CS}) = \pi (\gamma + 1) I_{CS} \quad (11)$$

$$S_{1,2} = 1, L_{1,2} = -1, \quad S_{3,4} = 1, L_{3,4} = 1. \quad (12)$$

$$S_{\perp} = dI_{\perp} = d\gamma v^2 \quad S_{\parallel} = dI_{\parallel} = d\gamma v^2 \quad (12)$$

\* The values are given in Table 1, Appendix 4;  $d$  is the number of wound limbs and  $e$  takes account of the corners of rectangular coils when estimating the mean length of one turn of copper. For the latter, the round number 3 has been chosen in preference to  $\pi$ , to allow for the closer bedding at the corners. It would be still less if the iron were chamfered away.

## Rectangular Coils.

$$L_0 = \sqrt{\frac{S_1 S_2}{L_1 L_2}} = \left[ \frac{d \times y \times z}{(c \times y + 2 + 2z)(a \times x + b \times y + c)} \right]^{1/2} \quad (1)$$

$$I_{L_0} = \left[ \frac{(c \times y + 2 + 2z)(a \times x + b \times y + c)}{d \times y \times z} \right]^{1/2} \quad (2)$$

$$L_{L_0} = x \frac{I_{L_0}}{L_0} \quad (3)$$

$$I_{L_0} = y \frac{I_{L_0}}{L_0} \quad (4)$$

$$L_{L_0} = \frac{I_{L_0}}{L_0} \quad (5)$$

## Circular Coils.

$$L_0 = \left[ \frac{d \times y \times z}{4 \times y \times (1)(a \times x + b \times y + c)} \right]^{1/2} \quad (6)$$

$$I_{L_0} = \left[ \frac{4 \times y \times (1)(a \times x + b \times y + c)}{d \times y \times z} \right]^{1/2} \quad (7)$$

$$L_{L_0} = x \frac{I_{L_0}}{L_0} \quad (8)$$

$$I_{L_0} = y \frac{I_{L_0}}{L_0} \quad (9)$$

$$L_{L_0} = \frac{I_{L_0}}{L_0} \quad (10)$$

## 7. COST EQUATIONS.

For a given value of the fundamental length—that is for a given value of the efficiency with a given ratio of iron to copper loss—we have

$$\mathcal{L} = c_1 \sigma_1 V_{L_0} + c_2 \sigma_2 V_{L_0} \quad (11)$$

$$= c_1 \sigma_1 V_0 \times \frac{V_{L_0}}{L_0} \left\{ 1 + \frac{c_2 \sigma_2}{c_1 \sigma_1} \frac{V_{L_0}}{V_0} \right\} \quad (12)$$

$$\therefore \frac{\mathcal{L}}{c_1 \sigma_1 V_0} = \frac{L_1 S_1}{[S_1 S_2 / (L_1 L_2)]^{1/2}} \left\{ 1 + m \frac{L_2 S_2}{L_1 S_1} \right\} \quad (13)$$

$$\therefore \frac{\mathcal{L}}{\mathcal{L}_0} = \frac{L_1^2 L_2}{S_1^2 S_2} \left\{ 1 + m \frac{L_2 S_2}{L_1 S_1} \right\} \quad (14)$$

The fundamental cost,  $\mathcal{L}_0$ , is fixed when the fundamental length, the cost of the iron, and its space-factor are known; it does not depend on the type of transformer nor on its proportions. The expression on the right-hand side of the equation, conveniently termed the "cost function," is a mere number which does not depend on the actual size, efficiency, actual specific costs, or actual space-factors; but it varies with the type, proportions, and relative costs and relative space-factors. We have thus separated the cost into these two factors, which are affected by different variables, and need only consider one factor at a time when studying the effects of these variables. The cost function thus forms a convenient starting-point for comparing different types and different proportions.

By inserting values in terms of the constants  $a, b, c, d, e$  for any type, and the proportions  $x, y, z$ , and equating to zero the partial differential coefficients with respect to  $x, y$ , and  $z$ , we can obtain the cheapest proportions and the corresponding dimension coefficients. This was done in the original paper for 30 different types, namely ring-core types with cores in the forms of a circle, duodecagon, octagon, hexagon, pentagon, and square; simple, shell and core types of single-phase transformers; three-limb, tandem shell, and tandem core types of 2-phase and 3-phase transformers; each with circular coils and with rectangular coils. The mathematical analysis is far too long to repeat here, but to illustrate the method it has been given in an Appendix for the ring-core (Berry) types which were not included before. The ring types are simpler to deal with than the others because there is one variable less.

Fig. 2 shows how the minimum cost function varies with the specific cost ratio for all these types. Fig. 3 repeats

the curves for rectangular-coil types on logarithmic paper. The ratio between the cost functions for any two types can be very easily obtained from the latter diagram by setting up the vertical distance between the corresponding curves from the 1000 mark on the ordinate scale.

## 8. COMPARISON OF TYPES. SINGLE-PHASE.

Subject to the limitations discussed in connection with the assumptions made, and to the fact that, because a smaller transformer will, as a rule, get hotter than a larger one having the same losses, we may have to spend part of the saving obtained by employing a better type in reducing the losses and getting a higher efficiency, we can make the following general statements as to the different types available for single-phase working if we require to get the same efficiency with each. There is also a further modification for those types which do not permit as good space-factors as the others.

In all cases except that of the ring-coil type, rectangular coils are cheaper than circular or square coils. Without allowing for their better iron space-factor, the difference in favour of the best shape of rectangular coil as compared with circular ones is about 3 per cent for the 3-limb 3-phase transformer, 5 per cent for the core and shell types, and 9 per cent for the ring-core types. The best ratio of depth to width of the iron core varies extremely little for different conditions. It is 2.2 for the core, shell, and ring-core types, and 2.05 for the 3-limb 3-phase type.

An examination of Fig. 3 shows that the types may be divided into two groups, one containing the shell and ring-coil types, and the other the core, ring-core, and simple types. The vertical distance between the curves in one group is practically constant within the practical limits of specific cost ratio, showing that the ratios of the cost functions for those in one group are practically fixed.

The core and shell types cost almost the same when the costs per unit of gross volume of the copper and iron spaces are alike ( $m = 1$ ). With dearer iron space ( $m < 1$ ) the core type is inherently cheaper; but with dearer copper space ( $m > 1$ ) the advantage lies with the shell type. The difference amounts to about 10 per cent for  $m = 0.1$  and  $m = 2.5$ . Although the copper costs considerably more than the iron, it has usually a much smaller space-factor, with the result that the specific cost ratio does not often differ sufficiently from unity to make the saving in material by using one type in preference to the other of very great moment. The choice between them should therefore be settled entirely from practical

considerations such as convenience of manufacture, mechanical strength, etc.

The ring types are appreciably cheaper if the same space-factor be obtained, the difference being over 10

difficulty by cutting down the cross-section of the central core, thereby still further reducing the amount of material required for a given efficiency. In addition to being a more practical form than the square ring-core (Burnand)

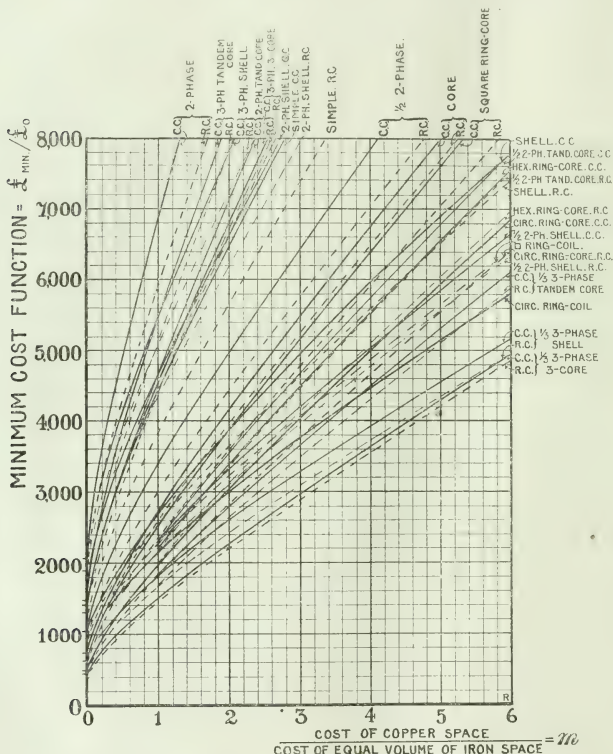


FIG. 2.—Minimum Values of the Cost Function.

(The full lines refer to transformers with circular coils and the dotted ones to those with rectangular coils.)

per cent for the square rings and more for the less practical circular rings. Difficulties of construction arise in the ring-core types (Faraday, Burnand), while in the circular ring-coil type (the original Berry type) there is the difficulty that the iron space cannot be well filled unless an impractically large number of different widths of sheet is employed. The square ring-coil type, as made by the General Electric Company of America, gets over this

type, it is also inherently cheaper when  $m$  exceeds unity.

#### 9. COMPARISON OF TYPES. POLYPHASE.

Polyphase transformers may be made by combining core or shell transformers one above the other, tandem fashion. The relative values of the core and shell types are exactly the same as for single-phase transformers. The cost-function of a 2-phase transformer is  $(2 + \sqrt{2})/4$

or 93 per cent, and that of a 3-phase transformer  $2/3$ , that of a bank of single-phase transformers of the same type giving the same efficiency. In the latter case, two complete 3-phase transformers (one in use and one spare) would require exactly the same active material as four single-phase transformers (three in use and one spare) of the same efficiency. The usual 3-limb type of 3-phase transformer is cheaper still, and costs less than a bank of single-phase ones of any type, allowing one spare in each case, provided the same efficiency be required in each case. Actually, the 3-phase transformer will get hotter

flux density is only  $1/\sqrt{3}$  times the actual density owing to the difference in phase between the fluxes in the two halves of the core.

The 3-limb type of 2-phase transformer is hopelessly out of the running as compared with the tandem types or banks of single-phase transformers.

#### 10. COMPARISON OF MATERIALS.

Near the usual values of the specific cost ratio, the logarithmic curves of the minimum cost function have a slope not far from  $\frac{1}{2}$ . Consequently we do not make much

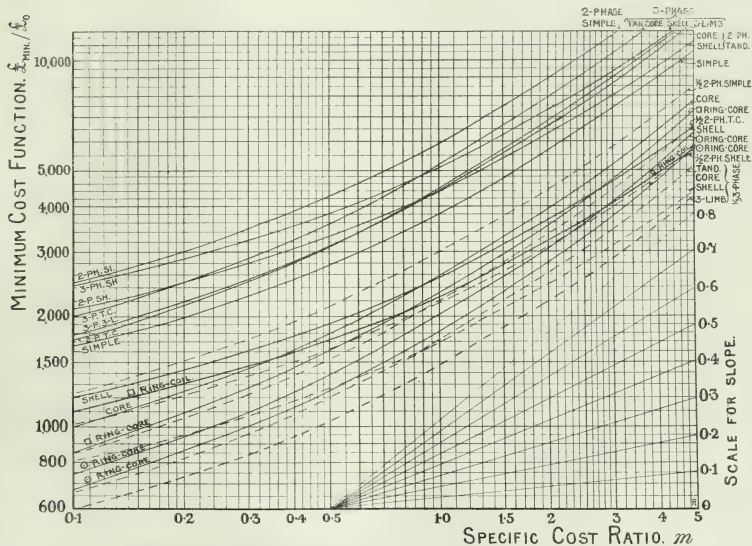


FIG. 3.—Logarithmic Curves of Minimum Values of Cost Functions of Transformers with Rectangular Coils.

than the single-phase ones; and if the latter are worked up to the full thermal limit, the 3-phase one would have to be designed for a higher efficiency. The minimum efficiency is higher for the 3-phase type because of these thermal considerations, and the engineers who prefer the bank of single-phase transformers are content with the lower efficiency which they permit. On the thermal basis the case is not quite so favourable to the 3-phase type, and a saving in capital cost can be shown by the adoption of separate transformers when allowance is made for spares.

There is also a symmetrical type of 3-limb 3-phase transformer having the centres of the coils placed at the corners of an equilateral triangle. But this is an expensive type, for in addition to its being difficult to construct, its effective

error in assuming that this function is proportional to the square root of  $m$ . By doing so, we can make tolerably accurate comparisons between one material and another, irrespective of the type of transformer or its size. If we make this assumption we can write:—

For a given efficiency

$$\mathcal{L} = (\mathcal{L}/\mathcal{L}_0) \times c_1 \sigma_1 L_0^2 \dots \dots \dots (23)$$

$$\propto (c_c \sigma_c)^{\frac{1}{2}} \times c_1 \sigma_1 \times \frac{L_0^2}{(\sigma_1 \sigma_c)} \dots \dots \dots (24)$$

$$\propto \frac{c_1^2 c_c^2}{\sigma_1 \sigma_c} L_0^2 \dots \dots \dots (25)$$

$$= \text{a constant if } L_0^2 \times c_1 c_c (\sigma_1^2 \sigma_c^2) \text{ is constant} \quad (26)$$

Allowing for the fact that a higher efficiency is necessary with the better material if the temperature rise is to be the same, it can be shown that:—

For a given temperature rise

$$L \propto c_1^3 c_2 L_1 \dots \dots \dots (27)$$

$$= \text{constant if } c_1 c_2 L_1 \text{ is constant} \dots \dots (28)$$

Applying these formulae to compare different thicknesses of sheet, and allowing for the reduced space-factor with thinner sheets, we find that at 50 cycles per second there is no advantage in reducing Stalloy below 20 mils. This agrees exactly with the experience of the makers. With Lohys it is worth while to use the thinnest obtainable sheets of about 12 mils.

Stalloy sheets 20 mils thick at a flux density of 0.645 millivolt-second per square inch (1 microvolt-second per square millimetre, or 10,000 C.G.S.) give a loss of 0.235 watt per cubic inch, while 15 mils Lohys gives 0.385. These give iron-loss coefficients of 0.566 and 0.925 watt-inch per (microvolt-second)<sup>2</sup>. Taking the resistivity of copper, hot and including an allowance for skin effect, as 0.9 microhm-inch, we get a loss-length of 3.21 mils for Stalloy, and 4.70 for Lohys.

Thus, for equal efficiencies, Stalloy would have to cost more than (4.70/3.21)<sup>3</sup> or 4.33 times Lohys before it would really be the more expensive material for this purpose. For a given temperature rise, the figure is (4.70/3.21)<sup>2</sup> or 1.63.

Let us see how aluminium would do in place of copper. We shall make a rather greater allowance for skin effect as the conductors will be thicker, and take the resistivity, hot, at 1.60 microhm-inches. With Stalloy, this gives a loss-length of 4.29 mils at 50 cycles per second, against 3.21. Since (4.29/3.21)<sup>2</sup> = 1.8 and (4.29/3.21)<sup>3</sup> = 5.7, aluminium must cost less than about half its volume of copper if it is to compete with it for transformer windings on a temperature basis, or than one-sixth on an efficiency basis. In other words, the price of aluminium per pound would have to be less than 18 per cent and 58 per cent respectively of that of copper. It will be noticed that the price is already sufficiently low to permit of its use when temperature rise is the primary criterion.

## 11. WINDING EQUATIONS.

The primary has to carry the exciting current in addition to the load current, but the secondary requires extra turns to make up for the voltage-drop. Putting one of these against the other, we shall not be far wrong if we take half the ampere-turns and half the cross-section of copper for each. The actual number of turns will require slight adjustment afterwards to get exactly the right voltage ratio. For our preliminary design we may thus put

$$N_1 I_1 = \frac{1}{2} I'' S_c = \frac{1}{2} \left( \frac{P_c}{\rho_c V_c} \right)^{\frac{1}{2}} S_c = \frac{1}{2} \left\{ \frac{P_c S_c}{\rho_c L_c} \right\}^{\frac{1}{2}} \dots (29)$$

$$\therefore N_1 = \frac{1}{2 I_1} \left\{ \frac{P_c S_c}{\rho_c L_c} \right\}^{\frac{1}{2}} \dots \dots \dots (30)$$

$$N_2 = \frac{1}{2 I_2} \left\{ \frac{P_c S_c}{\rho_c L_c} \right\}^{\frac{1}{2}} \dots \dots \dots (31)$$

And, for sandwiched coils

$$S_{w1} = S_c / (2 N_1), \quad S_{w2} = S_c / (2 N_2) \dots (32)$$

With concentric coils, 56 per cent of the total copper section should be given to the outer coil. If it is the primary we have

$$\begin{aligned} \text{Outer coil } S_{w1} &= 0.56 S_c / N_1, \\ \text{Inner coil } S_{w2} &= 0.44 S_c / N_1 \end{aligned} \dots \dots (33)$$

## 12. EXAMPLES OF DESIGN.

Suppose that we require a core transformer with rectangular coils for 100 kilovolt-amperes at 5,000/220 volts, 20.3/455 amperes, at 50 cycles per second, with copper and iron losses 750 watts each. We shall estimate the space-factors in the iron and copper spaces at 0.80 and 0.35 respectively, and take the loss-length at the value given in the table (page 144), namely 3.30 mils. Then

$$\begin{aligned} L_0 &= \frac{\Sigma I E \times L_1}{\sqrt{(P_c V_c) \sqrt{(\sigma_1 \sigma_2)}}} = \frac{2015 \text{ kw.} \times 3.30 \text{ mils}}{750 \text{ watts} \times \sqrt{(0.80 \times 0.35)}} \\ &= 1.68 \text{ inches.} \end{aligned}$$

For this type of transformer the round numbers 10, 5, 10/3, and 7.5 are almost exactly correct for  $L_{cs}/L_0$ ,  $2 I_{cs}/L_0$ ,  $I_{1s}/L_0$ , and  $L_{1s}/L_0$  with the proportions involved, which are not far from the cheapest ones for the usual values of the specific cost ratio.<sup>5</sup> Employing these numbers, we get:—

Distance between yokes =  $L_{cs} = 10 L_0 = 16.8$  in.

Distance between cores =  $2 I_{cs} = 5 L_0 = 8.4$  in.

Width of core =  $I_{1s} = (10/3) L_0 = 5.6$  in.

Depth of core =  $L_{1s} = 7.5 L_0 = 12.6$  in.

Net section of iron =  $S_1 = 0.80 \times 5.6 \times 12.6 = 56.5$  sq. in.

Net section of copper =  $S_c = 0.35 \times 16.8 \times 8.4 = 49.4$  sq. in.

Length of iron =  $L_1 = 33.4 + 16.8 + 22.4 = 72.6$  in.

Length of copper =  $L_c = 25.2 + 11.2 + 12.6 = 49.0$  in.

Net volume of iron =  $V_1 = 56.5 \times 72.6 = 4,100$  cub. in.

Net volume of copper =  $V_c = 49.4 \times 49.0 = 2,420$  cub. in.

$$\text{Turns in primary} = N_1 = \frac{1}{40.6} \left\{ \frac{750 \times 49.4}{0.90 \times 10^{-6} \times 49.0} \right\}^{\frac{1}{2}} = 714.$$

$$\text{Turns in secondary} = N_2 = \frac{1}{9.10} \left\{ \text{ditto} \right\}^{\frac{1}{2}} = 319.$$

Section of primary conductor =  $S_{w1} = 49.4/1428$

$$= 0.0346 \text{ sq. in.}$$

Section of secondary conductor =  $S_{w2} = 49.4/63.8$

$$= 0.774 \text{ sq. in.}$$

Current density =  $I'' = 20.3/0.0346 = 455/0.774$

$$= 588 \text{ amperes per sq. in.}$$

$$= 5,000 \text{ volts}$$

Flux density =  $B_m = 222 \text{ per sec.} \times 714 \times 50.5 \text{ sq. in.}$

$$= 0.560 \text{ millivolt-second per sq. in.}$$

$$= 8,680 \text{ lines per sq. cm.}$$

Specific iron loss =  $P_1/V_1 = 0.184 \text{ watt per cub. in. (Fig. 4).}$

Iron loss =  $P_1 = 0.184 \times 4,100 = 755 \text{ watts.}$

Copper loss =  $P_c = 0.9 \times 10^{-6} \times (588)^2 = 750 \text{ watts.}$

In this case the check results are very close indeed to our requirements, because the flux density happens to come very near to that for which the assumed loss-length is exactly right. The copper loss will always come quite right, for the winding formulae divide up the

<sup>5</sup> The exact values of these coefficients for  $\sigma = 3, 4$  and  $\sigma = 9.4$  are 10.06, 5.93, 3.35, 7.54. The cost-function is  $k/L_0 = 1,101 \pm 1.483 m$

which practically agrees with the minimum when  $m = 1$ , and exceeds it by less than 3 per cent within the limits  $m = 1.2$  and  $m = 2$ .

given copper in such a way as to give the specified loss with the given currents. To show the effect of the variation of the loss-length, let us take two other examples with the same dimensions but one with the iron loss only 500 watts and the copper loss 1,125 watts, while the other has these values interchanged. These have the same geometrical mean as before, and, since the aggregate volt-ampereage is not sensibly different, would have given the same fundamental length if we took the same loss-length, and so ought to fit into the same carcass if our theory had

one is about 5 per cent too small. The correct values of the loss-length at the flux densities of these two examples are 3.4 and 3.2 mils, respectively, instead of the 3.3 mils assumed. To comply with the conditions specified, the dimensions would have to be raised in the former case and lowered in the latter by about 3 per cent, making a change of nearly 10 per cent in the weight. We thus see that it is considerably more expensive to reduce the iron loss than to reduce the copper loss, because of the variation of the loss-length with flux density.

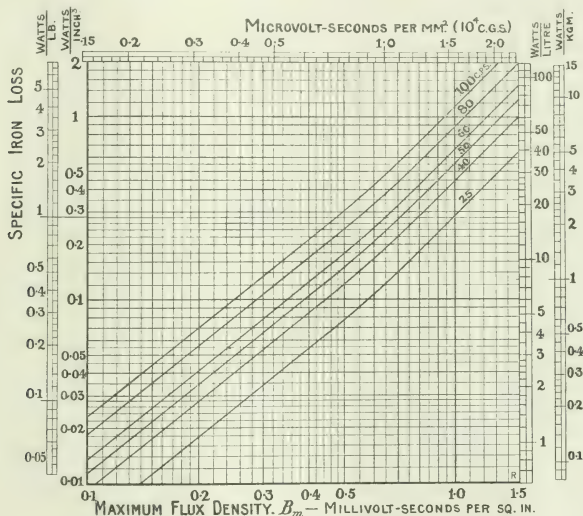


FIG. 4.—Specific Iron Loss with Sankey's "Stalloy" Iron, 20 mils thick.

been exact. Working out the things which are different, we get

	Low	High Iron Loss
Turns in primary = $N_1$	= 874	582.
Turns in secondary = $N_2$	= 39.0	20.0.
Section of primary conductor = $S_{w1}$	= 0.0282	0.0424 sq. in.
Section of secondary conductor = $S_{w2}$	= 0.623	0.949 sq. in.
Current density = $I''$	= 720	480 amperes per sq. in.
Flux density = $B_m$	= 0.456	0.685 m.v.s. per sq. in.
	= 7,080	10,600 C.G.S.
Specific iron loss = $P_i/V_i$	= 0.130	0.262 watt per cub. in.
Iron loss = $P_i$	= 534	1,070 watts.

It will be noticed that the low iron loss checks out about 7 per cent greater than what was wanted, while the high

The method is equally applicable to transformers with a number of distinct windings, to auto-transformers, and to choking coils. It is only necessary to know the aggregate load actually carried by all the windings (taking the maximum on each if they are not simultaneously loaded), and the total losses. The modifications required in the winding equations are obvious. In the case of the choking coil a gap must be placed in the magnetic circuit, conveniently a wooden or fibre distance piece, sufficient to bring up the exciting current with the rated voltage to the required current rating.

### 13. BEST DISTRIBUTION OF THE LOSSES.

The examples in the last section illustrate a point which is worth emphasizing. With given total losses, the geometrical mean loss is greatest when they are equally

divided between the copper and the iron. Consequently, if our assumptions were exactly true, the smallest transformer with a given efficiency would be obtained with equal division of the losses. Actually, the variation of the loss-length shifts the cheapest point in the direction of greater iron losses, so that, as the examples show, it is cheaper to reduce the copper loss than the iron loss.

Commonly, transformers are designed to have the iron losses less than half the full-load losses, with the object of reducing the energy lost during the 24 hours, which has the further advantage on a peaky load that the transformer is cooler after an interval of light load than it would be with greater iron losses. A saving of energy does not, however, necessarily mean a saving of money, but might lead to the reverse if the capital outlay necessary to obtain the saving is too great. In the extreme case of a hydro-electric station not requiring storage there is no appreciable difference between the total annual cost of supplying a 24-hour load (iron loss) and one which lasts only during the time of the peak load (copper loss), because the whole expense is made up of capital charges which depend on the maximum demand. In such a case, the transformer should be designed to give the highest efficiency under peak load conditions.

The case of a steam station is somewhat different, but even there the capital charges form a very important part of the total cost. High copper losses also mean a high voltage-drop on unity power factor.

#### 14. ADVANTAGES OF THE METHOD.

Most of the former writers on the subject have taken the product of the current and flux densities as the basis of their work, and some have even gone so far as to eliminate the losses, which may quite reasonably be supposed known, by expressing them in terms of the unknown current and flux densities. The present method reverses this latter process, and in addition to being more rational it leads to the following advantages:—

- (1) The effects of the following items on the cost are separated from one another so that each may be discussed without reference to the others:—output, losses, quality of the materials and frequency, space-factors, actual and relative costs of the materials, type of transformer, proportions of the transformer.
- (2) Consequently the relative values of different materials, different types, and different proportions with any one type can be settled once for all.
- (3) The fundamental length can be at once obtained from the given data.
- (4) The dimension coefficients by which the fundamental length must be multiplied to get the main dimensions of the transformer, whether it is decided to work to standard proportions or to take the cheapest for each case, have been or can be worked out once for all, so that the designer has only simple slide-rule operations to perform.

- (5) The only "trial and error" involved is that required by the estimate of suitable space-factors, and by the uncertainty as to the correct loss-length when the flux density is low.

#### 15. REPLY TO MR. LOW'S CRITICISMS.

On line 27 page 515 of Mr. Low's paper\* there appears one little word upon which the whole of his elaborate analysis depends, namely, "when" certain things are assumed constant, and these include the flux and current densities. Now it is quite easy to show that the cheapest values of the flux and current densities are much lower when a high efficiency is required than when a lower one is wanted for the same output. The absurdity of his assumption appears in the title to his very first problem (Section 18), "To find the dimensions corresponding to the minimum loss," under these conditions. By removing his arbitrary restriction and making the flux and current densities low enough—in other words by putting in sufficient material—the losses can be reduced without limit other than the commercial one of making the saving pay for itself. Mr. Low himself states this in Section 34, where he takes into account the possibility of getting a better result by varying the flux density and current density, but his criticisms of the present author's method are based on the earlier part of his paper, which entirely depends on the assumption that they are fixed.

It is scarcely to be expected that the results of a theory based on this assumption should be in full agreement with those from one which does not make it, nor is it justifiable to condemn the latter because they do not coincide with the former.

The basis of the author's differentiation is the assumption that the iron loss-coefficient is constant, or that the iron loss is proportional to the square of the flux density. Although not exactly true, especially at the lower flux densities, this assumption is much more rational than the one that the flux and current densities are always the same, and its error scarcely affects the theory up to the point at which differentiation begins, and only slightly then. The basis of the author's method is more general than Mr. Low's, for it is exactly true under the conditions which he assumes, and remains approximately true after his restrictions are removed. It thus carries the problem a stage further than his method.†

\* *Journal I.E.E.*, vol. 53.

† Since the above was written an article has appeared in the *Electrical World*, vol. 166, p. 456, 1015 (see also *Electrician*, vol. 75, p. 944, 1015), by S. Cabot and C. F. Carns entitled "The Design of Stationary Transformers." The authors of that article give a method of their own, and the results of a comparison with six other published methods, including that of the present author. In each case a design was worked out to the same data as one published by the authors of the respective methods, and in every case a cheaper transformer was obtained except in the case of the present author's, which they conclude is the only one "in which pains were taken to ascertain accurately the correct geometrical shape."

‡ This, and the article by Burnand already mentioned on page 145, should now be added to the very full bibliography given by Mr. Low on pages 520-1 of Volume 53 of the *Journal*.

## APPENDIX I.

## CHEMICAL PROPORTIONS OF CIRCULAR RING COIL TYPE OF TRANSFORMER.

If we assume that the iron space is filled up somewhat as in Fig. 5, we can see from the diagram that

$$S_{CS} = L - 1 = \pi y l_{CS} \dots \dots \dots (34) \quad L = \pi l_{CS} + 1 = \pi x + (1) l_{CS} \dots \dots \dots (36)$$

$$S_{IS} = \frac{\pi}{4} l_{IS} \dots \dots \dots (35) \quad L = 2 l_{CS} + 2 l_{IS} + 1 = (2x + 2y + 1) l_{CS} \dots \dots \dots (37)$$

where  $c$  is a constant which takes account of the excess of the mean length of the iron over its inner periphery.

$$\begin{aligned} \text{Then, } \frac{L}{S_{CS}} &= \frac{L - 1}{S_{CS}} + \frac{1}{S_{CS}} = \frac{(2x + 2y + 1) \times \pi x + 1}{\pi x} + \frac{1}{\pi x} = \frac{\pi (2x + 2y + 1) + 1}{\pi x} \\ &= \frac{2\pi (2x + 2y + 1) + 1}{\pi x} \left\{ 1 + \frac{1}{4mxy} \frac{(y + 1)}{(2x + 2y + 1)} \right\} \dots \dots \dots (38) \end{aligned}$$

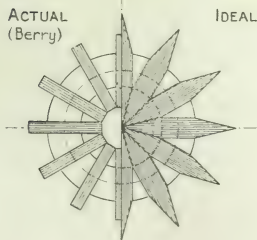
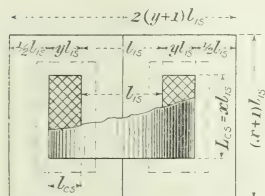


FIG. 5.—Circular Ring-coil Type of Transformer.

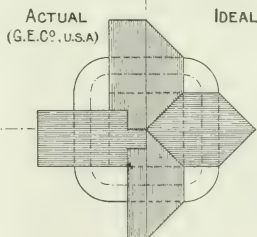
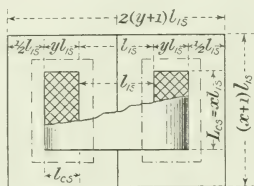


FIG. 6.—Square Ring-coil Type of Transformer.

For a minimum with different values of  $x$ ,

$$o = \frac{\partial}{\partial x} \left\{ \left[ \frac{(2x + 2y + 1)}{x} \right]^2 + 4mxy(y + 1) \left[ \frac{(2x + 2y + 1)}{x} \right]^2 \right\} \dots \dots \dots (39)$$

$$\begin{aligned} &= \left[ \frac{2x + 2y + 1}{x} \right]^{-2} \times \left[ x \times 10(2x + 2y + 1) - 3x(2x + 2y + 1) \right] \\ &\quad + 4mxy(y + 1) \left[ \frac{(2x + 2y + 1)}{x} \right]^{-2} \times \left[ x \times 6(2x + 2y + 1) - (2x + 2y + 1) \right] \dots \dots \dots (40) \end{aligned}$$

$$\therefore (2x + 2y + c) [10x - 3(2x + 2y + c)] = -4mxy(v + 1) [0v - (2x + 2y + c)] \quad (41)$$

$$\text{or,} \quad \frac{4mxy(v+1)}{(2x+2y+c)} = \frac{-10x+3(2x+2y+c)}{0v-(2x+2y+c)} \quad (42)$$

For a minimum with different values of  $y$ ,

$$0 = \frac{\partial}{\partial y} \left\{ \left[ \frac{(2x+2y+c)(v+1)}{y^2} \right]^2 + 4m^2 v \left[ \frac{(2x+2y+c)(v+1)}{y} \right]^3 \right\} \quad (43)$$

$$= \left[ \frac{(2x+2y+c)(v+1)^3}{y^3} \right] \times \left[ \frac{v \times 10(2x+2y+c)(v+1)^2 + v(2x+2y+c)^2 \times 3(v+1) - 3v \times 2x+2y+c(v+1)^3}{v^2} \right] \\ + 4m^2 v \left[ \frac{(2x+2y+c)(v+1)^2}{y^2} \right] \times \left[ \frac{v \times 0(2x+2y+c)(v+1)^2 + v(2x+2y+c)^2 \times 5(v+1)^2 - (2x+2y+c)(v+1)^3}{y^2} \right] \quad (44)$$

$$\therefore (2x + 2y + c) [10y(y + 1) - 3(2x + 2y + c)] = -4m^2 y(v + 1) [0v(v + 1) + (4y - 1)(2x + 2y + c)] \quad (45)$$

Dividing each side of Equation (41) by the corresponding one of Equation (45) and multiplying across, we get

$$[10v - 3(2x + 2y + c)] [0y(y + 1) + (4y - 1)(2x + 2y + c)] = [0v - (2x + 2y + c)] [10y(y + 1) - 3(2x + 2y + c)] \quad (46)$$

$$\therefore 0 = \frac{1}{y} [-8v(y + 1) + x(4y + 8)] (2x + 2y + c) - 12y(2x + 2y + c)^2 \quad (47)$$

$$\therefore v(4y + 8 - 24y) = 8y(y + 1) + 12v(2y + c) \quad (48)$$

$$\therefore v = \frac{4v \{ 2(y + 1) + 3(2y + c) \}}{8(2y + 1)} = \frac{v \{ 8y + (2 + 3c) \}}{2(2y + 1)} \quad (49)$$

$$\text{Hence,} \quad (2x + 2y + c) = \frac{v \{ 8y + (2 + 3c) \} + (2v + 1)(2y + c)}{(2v + 1)} = \frac{\{ 12y^2 + (4 + 5c)y + c \}}{(2y + 1)} \quad (50)$$

And, from (42),

$$m = \frac{(2x + 2y + c) [-10x + 3(2x + 2y + c)]}{4xy(y + 1) [0v - (2x + 2y + c)]} = \frac{\{ 12y^2 + (4 + 5c)y + c \} \{ -4y^2 + 2y + 3c \}}{2y^2(v + 1) \{ 8y + (2 + 3c) \} \{ 12y^2 + (2 + 4c)y - c \}} \quad (51)$$

which can be solved for assumed values of  $y$ .

Putting in (38) the values given by (49), (50), and (42), we get for the minimum cost function

$$\frac{L_{\min}}{L_0} = \frac{2\pi \left[ \frac{\{ 12y^2 + (4 + 5c)y + c \}}{(2y + 1)} \right]^2 (y + 1)^2}{\left[ \frac{v \{ 8y + (2 + 3c) \}}{2(2y + 1)} \right]^2 y^2} \left\{ 1 + \frac{-10x + 3(2x + 2y + c)}{-6x - (2x + 2y + c)} \right\} \quad (52)$$

$$= \frac{4\sqrt{2}\pi \{ 12y^2 + (4 + 5c)y + c \}^2 (y + 1)^2}{y^3(2y + 1) \{ 8y + (2 + 3c) \}^2} \left\{ \frac{2(2y + c)}{4x - (2y + c)} \right\} \quad (53)$$

$$= \frac{4\sqrt{2}\pi \{ 12y^2 + (4 + 5c)y + c \}^2 (y + 1)^2}{y^3(2y + 1) \{ 8y + (2 + 3c) \}^2} \left\{ \frac{2(2y + c)(2y + 1)}{2y \{ 8y + (2 + 3c) \} - (2y + c)(2y + 1)} \right\} \quad (54)$$

$$= \frac{8\sqrt{2}\pi (y + 1)^2 (2y + c) \{ 12y^2 + (4 + 5c)y + c \}^2}{y^3 \{ 8y + (2 + 3c) \} \{ 12y + (2 + 4c)y - c \}} \quad (55)$$

$$L_0 = \frac{S_{12} S_{cs}}{L_1 L_c} = \frac{\pi xy}{4(2x + 2y + c) \sqrt{\pi}(y + 1)} \text{ li} \quad (56)$$

Hence, for any chosen proportions,

$$\frac{I_{1s}}{L_{1s}} = \left[ \frac{4(y+1)(2y+2y+c)^2}{xy} \right]^{\frac{1}{2}} \dots \dots \dots (57)$$

and for the cheapest proportions,

$$\frac{I_{1s}}{L_{1s}} = \left[ \frac{8(y+1)^{\frac{1}{2}}(2y^2+(4+5c)y+c^2)}{y^{\frac{1}{2}}(8y+(2+3c))} \right] \dots \dots \dots (58)$$

$$\frac{L_{1s}}{L_{2s}} = \frac{I_{1s}}{I_{2s}} = \left[ \frac{2(y+1)^{\frac{1}{2}}(8y+(2+3c)^{\frac{1}{2}}(2y^2+(4+5c)y+c^2))^{\frac{1}{2}}}{(2y+1)} \right]^{\frac{1}{2}} \dots \dots \dots (59)$$

$$\frac{I_{1s}}{L_{1s}} : \frac{I_{2s}}{L_{2s}} = \left[ \frac{8(y+1)^{\frac{1}{2}}(2y^2+(4+5c)y+c^2)^{\frac{1}{2}}}{8y+(2+3c)^{\frac{1}{2}}} \right]^{\frac{1}{2}} \dots \dots \dots (60)$$

The numerical values given in the table are worked out for  $c=4/3$ , which applies to Fig. 5. In the original Berry transformer,  $c$  varies somewhat with the ratio of the width of sheet to the inner radius of the coil, but it does not lie very far from this value.

## APPENDIX 2.

### CHEAPEST PROPORTIONS OF SQUARE RING-COIL TYPE OF TRANSFORMER.

In this case (see Fig. 6) we have

$$S_{1s} = L_{1s} I_{1s} = xy I_{1s}^2 \dots \dots \dots (61) \quad L_C = (4 I_{1s} + c I_{2s}) = (4 + cy) I_{1s} \dots \dots \dots (63)$$

$$S_{2s} = I_{2s}^2 \dots \dots \dots (62) \quad L_I = (2 L_{1s} + 2 I_{2s} + c I_{1s}) = (2 + 2y + c) I_{1s} \dots \dots \dots (64)$$

$$\frac{L}{L_s} = \frac{L_C^2}{S_{1s} S_{2s}} \left\{ 1 + m \frac{L_C S_{2s}}{L_I S_{1s}} \right\} = \frac{(2x+2y+c)(cy+4)^2}{xy} \left\{ 1 + m xy \frac{(cy+4)}{(2x+2y+c)} \right\} \dots \dots \dots (65)$$

For a minimum with different values of  $x$ ,

$$0 = \frac{\partial}{\partial x} \left\{ \left[ \frac{(2x+2y+c)^2}{xy} \right]^{\frac{1}{2}} + m y (cy+4) \left[ \frac{(2x+2y+c)^2}{x} \right]^{\frac{1}{2}} \right\} \dots \dots \dots (66)$$

$$= \left[ \frac{(2x+2y+c)^2}{x} \right]^{-\frac{1}{2}} \times \left[ \frac{3 \times 10(2x+2y+c)^2}{x} - 3x^2 \frac{(2x+2y+c)^2}{x^2} \right] \\ + m y (cy+4) \left[ \frac{(2x+2y+c)}{x} \right]^{-\frac{1}{2}} \times \left[ \frac{x \times 6(2x+2y+c) - (2x+2y+c)^2}{x^2} \right] \dots \dots \dots (67)$$

$$\therefore (2x+2y+c) [10x - 3(2x+2y+c)] = -m xy (cy+4) [6x - (2x+2y+c)] \dots \dots \dots (68)$$

or

$$\frac{m y (cy+4)}{(2x+2y+c)} = \frac{-10x + 3(2x+2y+c)}{6x - (2x+2y+c)} \dots \dots \dots (69)$$

For a minimum with different values of  $y$ ,

$$0 = \frac{\partial}{\partial y} \left\{ \left[ \frac{(2x+2y+c)(cy+4)^2}{xy} \right]^{\frac{1}{2}} + m y \left[ \frac{(2x+2y+c)(cy+4)^2}{y} \right]^{\frac{1}{2}} \right\} \dots \dots \dots (70)$$

$$= \left[ \frac{(2x+2y+c)(cy+4)^2}{y} \right]^{-\frac{1}{2}} \times \left[ \frac{y^2 \times 10(2x+2y+c)(cy+4)^2 + y^2(2x+2y+c)^2 \times 3c(cy+4)^2 - 3y^3(2x+2y+c)^2(cy+4)^2}{y^2} \right] \\ + m y \left[ \frac{(2x+2y+c)(cy+4)^2}{y} \right]^{-\frac{1}{2}} \times \left[ \frac{y \times 6(2x+2y+c)(cy+4)^2 + y^2(2x+2y+c)^2 \times 5c(cy+4)^2 - (2x+2y+c)(cy+4)^2}{y^2} \right] \dots \dots \dots (71)$$

$$= (2x+2y+c) \left[ \frac{10y(cy+4)^2}{y} + 3cy(2x+2y+c) - 3(2x+2y+c)(cy+4) \right] \\ + m xy (cy+4) [6y(cy+4) + 5cy(2x+2y+c) - (2x+2y+c)cy+4] \dots \dots \dots (72)$$

$$\therefore (2x+2y+c) [10y(cy+4) - 12(2x+2y+c)] = -m xy (cy+4) [6y(cy+4) + 4(cy-1)(2x+2y+c)] \dots \dots \dots (73)$$

Dividing each side of Equation (68) by the corresponding one of (73), and multiplying across, we get

$$[10x - 3(2x + 2y + c)][6y(cy + 4) + 4(cy - 1)(2x + 2y + c)] = [6x - (2x + 2y + c)][10y(cy + 4) - 12(2x + 2y + c)] \quad (74)$$

$$\therefore 0 = -8cy(cy + 4) + 140cy + 32y^2(2x + 2y + c) - 12cy(2x + 2y + c)^2 \text{ and } 140cy + 32 - 24cy = 8y(cy + 4) + 12cy(2x + 2y + c) \quad (75)$$

$$\therefore 1 = \frac{4y^2(2cy + 4) + 3c(2y + c)^2}{10(cy + 2)} = \frac{y^2[8cy + (8 + 3c)]}{4(cy + 2)} \quad (76)$$

$$(2x + 2y + c) = \frac{y^2[8cy + (8 + 3c)] + 2(cy + 2)(2y + c)}{2(cy + 2)} = \frac{12cy^2 + (10 + 5c)y + 4c}{2(cy + 2)} \quad (77)$$

From (69),

$$\begin{aligned} m &= \frac{12x + 2y + c}{y(cy + 4)} \left[ -10x + 3(2x + 2y + c) \right] = \frac{2[12cy^2 + (10 + 5c)y + 4c]}{y^2(cy + 4)^2[8cy + (8 + 3c)]} \left[ -4cy^2 + 8y + 12x \right] \\ &= \frac{2[12cy^2 + (10 + 5c)y + 4c]^2}{y^2(cy + 4)^2[8cy + (8 + 3c)]} \left[ -cy^2 + 2y + 3c \right] \quad (78) \end{aligned}$$

Putting in (65) the values given by (76), (77), and (69), we get for the minimum cost function

$$\frac{L_{10}}{L_{100}} = \frac{\left[ \frac{12cy + (10 + 5c)y + 4c}{2(cy + 2)} \right]^2 (cy + 4)^2}{\left[ \frac{y^2[8cy + (8 + 3c)]}{4(cy + 2)} \right]^2} \left( 1 + \frac{-10x + 3(2x + 2y + c)}{6x - 2x - 2y - c} \right) \quad (79)$$

$$= \sqrt{\frac{2(cy + 4)^2[12cy^2 + (10 + 5c)y + 4c]^2}{y^2(cy + 2)^2[8cy + (8 + 3c)]^2}} \left[ \frac{2(2y + c)}{4y - (2y + c)} \right] \quad (80)$$

$$= \sqrt{\frac{2(cy + 4)^2[12cy^2 + (10 + 5c)y + 4c]^2}{y^2(cy + 2)^2[8cy + (8 + 3c)]^2}} \left[ \frac{2(2y + c)(cy + 2)}{4y[8cy + (8 + 3c)] - (2y + c)(cy + 2)} \right] \quad (81)$$

$$= \sqrt{\frac{2(cy + 4)^2(2y + c)[12cy^2 + (10 + 5c)y + 4c]^2}{y^2[8cy + (8 + 3c)]^2[3cy^2 + (2 + c)y - c]}} \quad (82)$$

$$L_{10} = \frac{S_{10} S_{100}}{L_{10} L_{100}} = \frac{xy}{(2x + 2y + c)(cy + 4)} \quad (83)$$

Hence, for any chosen proportions,  $\frac{L_{10}}{L_{100}} = \left[ \frac{(cy + 4)(2x + 2y + c)^2}{xy} \right]^2 \quad (84)$

and for the cheapest proportions,

$$\frac{L_{10}}{L_{100}} = \left[ \frac{2(cy + 4)[12cy^2 + (10 + 5c)y + 4c]}{y^2[8cy + (8 + 3c)]} \right]^2 \quad (85)$$

$$\frac{L_{10}}{L_{100}} = \frac{L_{10}}{L_{100}} = \left[ \frac{(cy + 4)[8cy + (8 + 3c)]}{8(cy + 2)^2} \frac{12cy^2 + (10 + 5c)y + 4c}{y} \right]^2 \quad (86)$$

$$\frac{L_{10}}{L_{100}} = \frac{L_{10}}{L_{100}} = \left[ \frac{2(cy + 4)[12cy^2 + (10 + 5c)y + 4c]}{y[8cy + (8 + 3c)]} \right]^2 \quad (87)$$

The numerical values given in the tables are worked out for  $c = 4/3$  and  $e = 3$ .

## APPENDIX 3.

## GRADED CURRENT DENSITY.

(1) *Ideal distribution of current.*—If we have a given section of copper, the losses will be least when the current is distributed in such a way that the current density varies inversely as the length of the turn. For, in that case, filaments which carry equal currents will have sections proportional to their length and will consequently have equal resistances and equal losses. This is the way in which a steady current will distribute itself across the cross-section if all the turns are in parallel.

Let a fraction  $x$  of the current in such a filament be removed to any other similar filament. The currents in the two filaments will now be  $(1-x)$  and  $(1+x)$  of what they were before, and the losses will be increased from  $1^2 + 1^2$  to  $(1-x)^2 + (1+x)^2$  of their former total value. The losses are thus increased by the fraction  $x^2$ , which is essentially positive. Thus, any distribution of the current other than the one we have supposed must give a greater loss than it does; but the difference is small, being proportional to  $x^2$ . An increase of the density over one-half of the current by 10 per cent and a corresponding diminution over the remaining half would only increase the losses by 1 per cent.

Let the inner perimeter of the winding space be  $L_1$  and its outer one

$$L_2 = (1+k)L_1 \quad (88)$$

Then at a fraction  $x$  of the total winding depth out from the inside perimeter,

$$L = (1+kx)L_1 \quad (89)$$

and the current density at this place is

$$I = I_1'' \times (L_1/L) = I_1''/(1+kx) \quad (90)$$

The average current density up to this point is

$$I_{av} = I_1'' \int_0^x \frac{dx}{1+kx} = I_1'' \times \frac{\log(1+kx)}{k} \quad (91)$$

and the average throughout the whole winding is

$$I_1' = I_1'' \int_0^1 \frac{dx}{1+kx} = I_1'' \times \frac{\log(1+k)}{k} \quad (92)$$

In order that the fraction  $p$  of the whole current may be included in the space up to the place  $x$

$$\log(1+kx) = p \log(1+k) \quad (93)$$

or

$$(1+kx) = (1+k)^p \quad (94)$$

$$x = \frac{(1+k)^p - 1}{k} \quad (95)$$

Hence, of the total current there is included

$$\text{one-fourth up to } x = (1+k)^{1/4} - 1 \quad (96)$$

$$\text{one-half up to } x = (1+k)^{1/2} - 1 \quad (97)$$

$$\text{and three-fourths up to } x = (1+k)^{3/4} - 1 \quad (98)$$

The loss in any filament is proportional to

$$L(I'')^2 = L_1(I_1'')^2 \div (1+kx) \quad (99)$$

$\therefore$  mean  $L(I'')^2$

$$= L_1(I_1'')^2 \int_0^1 \frac{dx}{1+kx} = L_1(I_1'')^2 \times \frac{\log(1+k)}{k} \quad (100)$$

$$= \frac{(1 + \frac{1}{2}k)L_1}{(1 + \frac{1}{2}k)} \left\{ \frac{I_1'' \times \log(1+k)}{k} \right\}^2 \times \frac{k}{\log(1+k)} \quad (101)$$

$$= L_1(I_1'')^2 \times \frac{1}{k} \left( 1 + \frac{1}{2}k \log(1+k) \right) \quad (102)$$

Loss with uniform distribution

Loss with ideal distribution

$$= \frac{L_1(I_1'')^2}{\text{mean } L(I'')^2} = \frac{(1 + \frac{1}{2}k \log(1+k))}{k} \quad (103)$$

(2) *Ideal concentric coils.*—Let the total area of copper be divided between two coils in accordance with Equation (97), and then let each have half the total flow of current distributed uniformly over it. If  $S$  be the total section of copper, the portions in each coil are

$$(1+k)^{1/2} - 1 \quad S/k \quad \text{and} \quad (1+k)^{1/2} - 1 \quad S/k \quad (104)$$

$$\text{or, } (1+k)^{1/2} - 1 \quad S/k \quad \text{and} \quad (1+k)^{1/2} - 1 \quad S/k \quad (105)$$

The common perimeter of the two coils is

$$(1+k)^{1/2} L_1 \quad (106)$$

and their mean perimeters

$$\frac{1}{2} \left\{ (1+k)^{1/2} + 1 \right\} L_1 \quad \text{and} \quad \frac{1}{2} \left\{ (1+k) + (1+k)^{1/2} \right\} L_1 \quad (107)$$

$$\text{or, } \frac{1}{2} \left\{ (1+k)^{1/2} + 1 \right\} L_1 \quad \text{and} \quad \frac{1}{2} \left\{ (1+k)^{1/2} + (1+k)^{1/2} + 1 \right\} L_1 \quad (108)$$

Bearing in mind that each carries half the total current through the window, the total losses are proportional to

$$\left( \frac{1}{2} \right)^2 \times \frac{\frac{1}{2} \left\{ (1+k)^{1/2} + 1 \right\} L_1}{\frac{1}{2} \left\{ (1+k)^{1/2} - 1 \right\} S/k} + \left( \frac{1}{2} \right)^2 \times \frac{\frac{1}{2} \left\{ (1+k) + (1+k)^{1/2} \right\} L_1}{\frac{1}{2} \left\{ (1+k)^{1/2} - 1 \right\} S/k} \quad (109)$$

$$= \frac{\frac{1}{4} \left\{ (1+k)^{1/2} + 1 \right\} L_1}{4 \left\{ (1+k)^{1/2} - 1 \right\} S/k} = \frac{\frac{1}{4} \left\{ (1+k)^{1/2} + 1 \right\} L_1}{4S} \quad (110)$$

It will be noticed that the losses are the same in the two coils.

With uniform distribution throughout the whole winding, the losses would be proportional to

$$\frac{1}{4} \left\{ (1+k) + 1 \right\} L_1 S = \frac{1}{4} (2+k) L_1 S \quad (111)$$

Hence,

$$\text{Loss with uniform distribution} = \frac{2(2+k)}{(1+k)^{1/2} + 1} \quad (112)$$

$$\text{Loss with two-step grading} = \frac{1}{(1+k)^{1/2} + 1}$$

If we divide the current between three coils, of which the innermost and outermost carry one-fourth each and

the middle coil one-half as in a subdivided concentric winding, and take the areas in accordance with Equations (96) and (98), the total sections of copper in the coils are

$$\begin{aligned} & \frac{1}{2} \left\{ (1+k)^2 - 1 \right\} S/k, \quad \frac{1}{2} \left\{ (1+k)^2 - (1+k)^2 \right\} S/k, \\ & \text{and } \frac{1}{2} \left\{ (1+k) - (1+k)^2 \right\} S/k \quad (113) \end{aligned}$$

$$\begin{aligned} \text{or, } & \frac{1}{2} \left\{ (1+k)^2 - 1 \right\} S/k, \quad (1+k)^2 \left\{ (1+k)^2 - 1 \right\} S/k, \\ & \text{and } (1+k)^2 \left\{ (1+k)^2 - 1 \right\} S/k \quad (114) \end{aligned}$$

The four perimeters are

$$L_1, \quad (1+k)^2 L_1, \quad (1+k) L_1, \quad \text{and } (1+k) L_1 \quad (115)$$

and the mean perimeters

$$\begin{aligned} & \frac{1}{2} \left\{ (1+k)^2 + 1 \right\} L_1, \quad \frac{1}{2} \left\{ (1+k)^2 + (1+k)^2 \right\} L_1, \\ & \text{and } \frac{1}{2} \left\{ (1+k) + (1+k) \right\} L_1 \quad (116) \end{aligned}$$

$$\begin{aligned} \text{or, } & \frac{1}{2} \left\{ (1+k)^2 + 1 \right\} L_1, \quad \frac{1}{2} \left\{ (1+k)^2 \left\{ (1+k)^2 + 1 \right\} \right\} L_1, \\ & \text{and } \frac{1}{2} \left\{ (1+k)^2 \left\{ (1+k)^2 + 1 \right\} \right\} L_1 \quad (117) \end{aligned}$$

Hence, the total losses are proportional to

$$\begin{aligned} & \left( \frac{1}{2} \right)^2 \times \frac{1}{2} \left\{ (1+k)^2 + 1 \right\} L_1 \quad + \quad \left( \frac{1}{2} \right)^2 \times \frac{1}{2} \left\{ (1+k)^2 + 1 \right\} L_1 \\ & \left\{ (1+k)^2 - 1 \right\} S/k \quad + \quad \left\{ (1+k)^2 - 1 \right\} S/k \\ & + \left( \frac{1}{2} \right)^2 \times \frac{1}{2} \left\{ (1+k)^2 + 1 \right\} L_1 \\ & \left\{ (1+k)^2 - 1 \right\} S/k \quad (118) \end{aligned}$$

$$= \frac{L_1}{16S} \left[ \left\{ (1+k)^2 + 1 \right\}^2 + \left\{ (1+k)^2 + 1 \right\} \right] \quad (119)$$

$$= \frac{L_1}{16S} \left[ \left\{ (1+k)^2 + 1 \right\}^2 + 2 \left\{ (1+k)^2 + 1 \right\} \right] \quad (120)$$

$$= (L_1/16S) \left\{ 3(1+k)^2 + 2(1+k)^2 + 3 \right\} \left\{ (1+k)^2 + 1 \right\} \quad (121)$$

Hence,

Loss with uniform distribution

Loss with three-step grading

$$= \frac{8(2+k)}{\left\{ (1+k)^2 + 1 \right\} \left\{ 3(1+k)^2 + 2(1+k)^2 + 3 \right\}} \quad (122)$$

It will be seen that the losses in the innermost and outermost coils are the same, but that the middle coil has a greater loss than the sum of the other two. With ideal distribution the losses in the coils would be in the same ratio as the total currents they carry, namely 1:2:1. On changing to uniform distribution in each, the losses in the two small coils are affected to the same extent because they have the same ratio of outer to inner perimeter, viz.  $(1+k)^2$ . But the central coil has a greater ratio,  $(1+k)^3$ , and consequently its loss is increased in a greater proportion than those of the other two coils, with the result that it now exceeds their sum. If we had divided the

central coil into two, each taking one-fourth of the total current, in accordance with Equation (97), the perimeter ratio would then be the same for all four coils. Their losses would then be equal and the total loss four times that in one of them. The total loss is then proportional to

$$\begin{aligned} & 4 \times \left( \frac{1}{2} \right)^2 \times \frac{1}{2} \left\{ (1+k)^2 + 1 \right\} L_1 \\ & \left\{ (1+k)^2 - 1 \right\} S/k \\ & = \frac{1}{8} \left\{ (1+k)^2 + 1 \right\}^2 L_1 \\ & \left\{ (1+k)^2 - 1 \right\} S/k \quad (123) \\ & = \frac{1}{8} \left\{ (1+k)^2 + 1 \right\}^2 \left\{ (1+k)^2 + 1 \right\} L_1/8S \quad (124) \end{aligned}$$

Hence,

Loss with uniform distribution

Loss with four-step grading

$$= \frac{4(2+k)}{\left\{ (1+k)^2 + 1 \right\}^2 \left\{ (1+k)^2 + 1 \right\}} \quad (125)$$

Numerical values for the correct apportionment of the copper to each coil, and of the saving in loss which each of these arrangements gives as compared with uniform current density, are given in Table 6, Appendix 4. It will be seen that even with ideal distribution the saving is quite small unless the perimeter ratio is excessive.

(3) *Concentric coils with graded current density.*—Consider the case of two concentric coils, which may or may not have the same shape. Then, let

Total section of copper be  $S$  . . . . . (126)

Total section in inner coil  $S_1$  . . . . . (127)

Total section in outer coil  $S_2 = S - S_1$  . . . . . (128)

Inner perimeter of inner coil be  $L_1$  . . . . . (129)

Mean perimeter " "  $L_1 + g_1 S_1$  . . . . . (130)

Outer perimeter " "  $L_2 + 2 g_1 S_1$  . . . . . (131)

where  $g_1$  is a constant depending on the shape of the coil and on the net space-factor for the coil.

The inner perimeter of the outer coil exceeds the outer perimeter of the inner coil by an amount  $a$ , which is proportional to the clearance between them but also depends on the shapes of the coils. We shall assume that the clearance between the two coils is fixed by mechanical and insulation considerations and that  $a$  is therefore a constant. The outermost perimeter will thus vary slightly with the way in which the copper is distributed between the two coils in those cases in which the quantity  $g$  is not the same for both. We shall also assume that the total cross-section, and not the total volume, of copper is fixed. This is the natural assumption for transformers in which the whole window should be filled except for necessary clearances.

For the outer coil we thus have

Inner perimeter  $L_2 + a + 2 g_1 S_1$  . . . . . (132)

Mean perimeter  $L_2 + a + 2 g_1 S_1 + g_2 S_2$  . . . . . (133)

Outer perimeter  $(1+k)L_1 = L_2 = L_2 + a + 2 g_1 S_1 + 2 g_2 S_2$  . . . . . (134)

From which we see that

$$k = (a + 2 g_1 S_1 + 2 g_2 S_2)/L_1 \quad (135)$$

When, as is usual, the high-voltage coil is placed outside,  $q_s$  will be somewhat greater than  $q_i$  because of the greater portion of space required for insulation leading to a greater winding depth for a given total section of copper. In the special case

$$\text{when } q_i = q_s, \text{ then } k = (a + 2 q_i S) / L_i \quad (136)$$

If we assume that the total flow of current through the window is the same for both coils, then the loss in each is proportional to the resistance it would have if all the metal became fused into a single turn but nothing else altered. Hence the copper losses are proportional to

$$L_i + c, S_i + L_i + a + 2 q_i S + (q_s - 2 q_i) S_i \quad (137)$$

$$= L_i / S_i + (L_i + a + 2 q_i S) / S_i + (q_s - 2 q_i) \quad (138)$$

For a minimum we must differentiate with respect to  $S_i$  and equate to zero, thus

$$0 = -L_i / S_i^2 - (L_i + a + 2 q_i S) / S_i^3 (d S_i / d S_i) \quad (139)$$

$$= -L_i / S_i + (L_i + a + 2 q_i S) / S_i^2 \quad (140)$$

$$\therefore L_i / S_i = (L_i + a + 2 q_i S) / S_i^2 \quad (141)$$

$$\text{or } S_i / S_i = \{1 + (a + 2 q_i S) / L_i\}^{1/2} \quad (142)$$

$$\begin{aligned} \therefore \frac{S_i}{S_i} &= \frac{S_i}{S_i + S_i} = \frac{1}{1 + \{1 + (a + 2 q_i S) / L_i\}^{1/2}} \\ &= \frac{1 + (a + 2 q_i S) / L_i}{1 + \{1 + (a + 2 q_i S) / L_i\}^{1/2}} \quad (143) \end{aligned}$$

$$\text{and } \frac{S_s}{S_i + S_s} = \frac{1}{1 + \{1 + (a + 2 q_i S) / L_i\}^{1/2}} \quad (144)$$

In the special case these become

$$\text{when } q_i = q_s$$

$$S_i / S_i = (1 + k)^{-1/2} \quad (145)$$

$$S_i / S_i = \{1 + (1 + k)^{1/2}\}^{-1} = \{1 + k\}^{-1/2} \quad (146)$$

$$S_i / S_i = \{1 + k\}^{-1/2} \{1 + (1 + k)^{1/2}\} = \{1 + k\}^{-1/2} \{1 + k\}^{-1/2} = \{1 + k\}^{-1} \quad (147)$$

Comparing Equations (97) and (146) we see that the division of the copper in this special case of concentric coils is the same as with ideal distribution. We shall not be far wrong if we also apply the latter results to the case of subdivided concentric coils, for which the equations obtained by methods similar to those given here are exceedingly cumbersome. It is of interest to note that Equations (145)–(147) apply exactly even when  $q_i$  and  $q_s$  are not alike, provided the outer perimeter be kept fixed and the clearance between the coils be varied to make up for

differences of total winding depth with different values of  $S_i / S_s$ .

Making use of Equation (141) in (137) we see that with the best distribution of the copper the losses in the two coils are proportional to

$$L_i / S_i + q_i \quad \text{and} \quad \{L_i / S_i + (q_s - 2 q_i)\} \quad (148)$$

The excess of the loss in the outer coil over that in the inner coil is thus proportional to

$$\begin{aligned} L_i S_i / S_i^2 - L_i / S_i + (q_s - 2 q_i) \\ = L_i (S_i - S_i) / S_i^2 + (q_s - 2 q_i) \quad (149) \end{aligned}$$

$$= L_i (S_i - S_i) (S_i + S_i) / S_i^2 S + (q_s - 2 q_i) \quad (150)$$

$$= L_i (S_i^2 / S_i - 1) / S + (q_s - 2 q_i) \quad (151)$$

$$= L_i \{1 + (a + 2 q_i S) / L_i\} / S + (q_s - 2 q_i) \quad (152)$$

$$= a / S + (q_s - q_i) \quad (153)$$

It is usually supposed that the losses in the two coils should be alike for a minimum total loss, but we see that this can never be the case with an actual pair of coils having the high-voltage coil outside. The quantity  $a$  is essentially positive and  $q$  is greater for the high-voltage coil than for the other. The usual statement only applies to the ideal case for which it has been deduced, namely that in which there is no clearance between the coils and in which the two  $q$ 's are alike.

By putting  $S_i = S_s = \frac{1}{2} S$  in expression (138) we get a value proportional to the losses with an equal division of copper section between the two coils, namely,

$$2 L_i / S + 2 (L_i + a) / S + (q_s + 3 q_i) \quad (154)$$

$$= 2 (2 L_i + a) / S + (q_s + 3 q_i) \quad (155)$$

Hence, using Equations (148) and (143) we get

Loss with equal division of copper

Loss with best division of copper

$$= \frac{2 (2 L_i + a) + (q_s + 3 q_i) S}{\{L_i (S_i + S_s) / S_i^2 + (q_s - q_i)\} S} \quad (156)$$

$$= \frac{2 (2 L_i + a) + (q_s + 3 q_i) S}{L_i S_i^2 / S_i + (q_s - q_i) S} \quad (157)$$

$$= \frac{2 (2 + a / L_i) + (q_s + 3 q_i) S / L_i}{\{1 + \{1 + (a + 2 q_i S) / L_i\}^{1/2}\}^2 + (q_s - q_i) S / L_i} \quad (158)$$

In the special case in which  $q_i = q_s$ , this becomes

$$\frac{2 (2 + a / L_i) + 4 q_i S / L_i}{\{1 + (1 + k)^{1/2}\}^2} = \frac{2 (2 + k)}{\{1 + (1 + k)^{1/2}\}^2} \quad (159)$$

This is the same as Equation (112). We thus see that the numerical values of Table 6, which were obtained for ideal concentric coils without clearance, apply also to real coils with clearance provided  $q_i = q_s$ .

## APPENDIX 4.—TABULAR DATA.

TABLE 1.

*Coefficients a, b, c, d, e for Shell and Core Transformers.*

Type	a	b	c	d	e
Simple ... ..	2	2	4	1	3
Shell ... ..	2	2	2	1	3
Core ... ..	2	4	4	2	3
2-phase simple ... ..	$(2 + \sqrt{2})$	4	$2(2 + \sqrt{2})$	2	3
" tandem shell ... ..	4	$(2 + \sqrt{2})$	$(2 + \sqrt{2})$	2	3
" tandem core ... ..	4	$2(2 + \sqrt{2})$	$2(2 + \sqrt{2})$	4	3
3-phase 3-core ... ..	4	8	6	3	3
" tandem shell ... ..	6	4	4	3	3
" tandem core ... ..	6	8	8	6	3

TABLE 2.

*Ring-coil Transformers with Minimum Cost-function.*

Specific Cost-ratio <i>m</i>	SQUARE COILS				CIRCULAR COILS			
	Dimension Coefficients			Cost-function <i>L<sub>min</sub>/L<sub>0</sub></i>	Dimension Coefficients			Cost-function <i>L<sub>min</sub>/L<sub>0</sub></i>
	<i>I<sub>1</sub>, I<sub>2</sub></i>	<i>I<sub>1</sub>, L<sub>1</sub></i>	<i>I<sub>2</sub>, L<sub>2</sub></i>		<i>I<sub>1</sub>, L<sub>1</sub></i>	<i>L<sub>1</sub>, L<sub>2</sub></i>	<i>I<sub>1</sub>, L<sub>2</sub></i>	
0	4'32	14'28	6'64	880	4'87	14'23	6'24	885
0'1	4'85	11'00	5'05	1,100	5'50	11'25	4'75	1,080
0'2	5'15	10'10	4'60	1,300	5'80	10'30	4'30	1,250
0'4	5'50	9'15	4'13	1,590	6'15	9'54	3'90	1,510
0'6	5'87	8'66	3'84	1,840	6'44	9'05	3'66	1,740
0'8	6'07	8'35	3'68	2,060	6'65	8'72	3'50	1,950
1'0	6'25	8'10	3'57	2,280	6'85	8'48	3'38	2,130
1'2	6'41	7'91	3'48	2,490	7'00	8'29	3'30	2,310
1'4	6'55	7'76	3'40	2,680	7'14	8'14	3'22	2,490
1'6	6'67	7'62	3'33	2,870	7'26	8'01	3'16	2,660
1'8	6'77	7'50	3'28	3,050	7'37	7'90	3'11	2,820
2'0	6'88	7'40	3'24	3,230	7'48	7'80	3'06	2,980
2'2	6'98	7'32	3'20	3,410	7'58	7'72	3'02	3,140
2'4	7'06	7'25	3'16	3,580	7'67	7'64	2'98	3,300
2'6	7'14	7'18	3'12	3,750	7'76	7'57	2'95	3,460
2'8	7'22	7'11	3'09	3,920	7'85	7'50	2'92	3,610
3'0	7'29	7'05	3'06	4,090	7'93	7'45	2'89	3,760
3'5	7'40	6'94	3'00	4,490	8'10	7'33	2'83	4,120
4	7'60	6'85	2'96	4,890	8'26	7'24	2'79	4,470
5	7'85	6'70	2'88	5,680	8'54	7'07	2'74	5,150
10	8'67	6'26	2'68	9,330	9'33	6'68	2'52	8,320
$\infty$	12'43	5'24	2'19	$\infty$	13'70	5'57	2'01	$\infty$

TABLE 3.  
Shell Transformers with Minimum Core-function.

Specimen Coefficient $m$	SINGLE PHASE					TWO-PHASE					THREE-PHASE				
	Rectangular Coils			Circular Coils		Rectangular Coils		Circular Coils		Core-function $\frac{L_{\text{core}}}{L_{\text{coil}}}$	Rectangular Coils		Circular Coils		Core-function $\frac{L_{\text{core}}}{L_{\text{coil}}}$
	$L_{\text{in}}, L_{\text{out}}$	$L_{\text{in}}, L_{\text{out}}$	$L_{\text{in}}, L_{\text{out}}$	$L_{\text{in}}, L_{\text{out}}$	$I_{\text{in}}, I_{\text{out}}$	$L_{\text{in}}, L_{\text{out}}$	$L_{\text{in}}, L_{\text{out}}$	$L_{\text{in}}, L_{\text{out}}$	$L_{\text{in}}, L_{\text{out}}$		$L_{\text{in}}, L_{\text{out}}$	$L_{\text{in}}, L_{\text{out}}$	$L_{\text{in}}, L_{\text{out}}$	$L_{\text{in}}, L_{\text{out}}$	
0	3.84	14.82	7.04	6.70	9.10	4.71	17.68	7.07	1.038	1.666	1.881	9.88	1.756	11.79	2.037
0.1	3.28	11.40	5.70	5.55	14.00	5.25	13.50	5.25	1.350	2.070	2.130	7.96	2.300	9.33	2.700
0.2	3.51	10.43	4.82	8.02	14.20	5.64	12.87	4.68	1.550	8.92	2.130	6.05	2.600	8.58	3.100
0.3	3.80	9.42	4.31	8.60	17.10	6.02	11.88	4.10	1.900	8.93	2.470	6.28	3.240	7.82	3.880
0.6	4.01	8.84	4.02	9.03	20.30	6.20	11.30	3.93	2.200	7.55	3.060	5.99	3.750	7.53	4.490
0.8	4.17	8.52	3.86	9.53	22.00	6.50	10.97	3.73	2.480	7.27	3.010	5.68	4.670	7.14	4.960
1.0	4.30	8.36	3.73	9.80	23.00	6.68	10.72	3.62	2.740	7.05	3.130	5.51	5.080	6.86	5.180
1.2	4.41	8.26	3.63	9.82	23.80	6.83	10.50	3.52	3.000	6.88	3.230	5.38	5.560	6.59	5.480
1.4	4.51	8.19	3.55	10.02	24.00	6.94	10.33	3.44	3.220	6.75	3.340	5.28	6.020	6.30	5.880
1.6	4.60	8.13	3.48	10.10	24.00	7.08	10.17	3.37	3.460	6.64	3.470	5.19	6.460	6.09	6.280
1.8	4.68	8.07	3.43	10.15	24.00	7.20	10.01	3.31	3.680	6.55	3.570	5.12	6.880	5.79	6.730
2.0	4.70	8.02	3.38	10.50	24.00	7.31	9.97	3.25	3.880	6.46	3.670	5.05	7.300	5.50	7.200
2.2	4.83	7.98	3.33	10.74	24.00	7.48	9.87	3.22	4.100	6.32	3.750	4.99	7.700	5.20	7.770
2.4	4.89	7.90	3.29	10.88	24.00	7.59	9.78	3.18	4.310	6.20	3.820	4.94	8.100	4.93	8.200
2.6	4.95	7.84	3.25	10.99	24.00	7.74	9.71	3.14	4.510	6.08	3.890	4.89	8.500	4.68	8.640
2.8	5.01	7.78	3.23	11.09	24.00	7.84	9.65	3.13	4.700	5.97	3.950	4.85	8.900	4.44	9.040
3.0	5.08	7.72	3.20	11.14	24.00	7.92	9.59	3.08	4.900	5.87	4.020	4.82	9.300	4.20	9.540
3.5	5.18	7.60	3.14	11.34	24.00	8.04	9.46	3.01	5.450	5.68	4.74	4.74	10.240	4.00	10.840
4	5.29	7.50	3.09	11.55	24.00	8.20	9.35	2.97	5.970	5.48	9.550	4.67	11.070	3.78	11.800
5	5.47	7.85	3.01	11.91	24.00	8.50	9.17	2.80	6.840	5.84	11.000	4.58	13.070	3.50	13.600
6	5.67	6.43	2.86	13.10	24.00	9.13	8.70	2.67	11.200	5.48	18.500	4.28	21.600	3.04	22.570
20	8.62	5.47	2.32	18.15	24.00	12.95	7.56	2.16	z	4.67	z	3.95	z	5.04	z

\* The other dimension coefficients are the same as for a single-phase transformer.

TABLE 4.  
Core Transformers with Minimum Cost-function.

Specific Cost ratio	SINGLE PHASE										TANDEM 2 PHASE				TANDEM 4 PHASE			
	Rectangular Coils					Circular Coils					Rectangular Coils		Circular Coils		Rectangular Coils		Circular Coils	
	Design Coefficients					Design Coefficients					Design Coefficients		Design Coefficients		Design Coefficients		Design Coefficients	
	$I_{01} I_{02}$	$I_{03} I_{04}$	$2 I_{01} I_{02}$	$I_{01} I_{03}$	$I_{01} I_{04}$	$I_{01} I_{02}$	$I_{03} I_{04}$	$2 I_{01} I_{02}$	$I_{01} I_{03}$	$I_{01} I_{04}$	$I_{01} I_{02}$	$I_{03} I_{04}$	$2 I_{01} I_{02}$	$I_{01} I_{03}$	$I_{01} I_{04}$	$I_{01} I_{02}$	$I_{03} I_{04}$	$2 I_{01} I_{02}$
0	2.01	2.096	9.95	4.74	6.65	3.33	3.99	18.20	6.04	10.00	727	1.890	1.710	1.435	1.907	1.870	1.241	1.454
0.1	2.48	4.476	6.83	5.67	1.000	4.26	16.80	5.92	1.340	1.000	1.340	1.290	1.710	1.870	0.84	1.214	2.197	2.197
0.2	2.68	13.33	6.10	6.68	1.250	4.50	15.58	5.30	1.750	1.340	1.340	1.38	2.140	2.200	8.80	2.500	2.680	2.680
0.4	2.94	12.05	5.45	6.60	1.640	4.81	14.85	4.99	2.100	2.100	1.750	10.38	2.800	2.080	8.03	3.280	3.500	3.500
0.6	3.12	11.40	5.13	6.65	1.970	4.81	14.85	4.99	2.430	2.430	1.750	9.74	3.300	3.380	7.60	3.940	4.200	4.200
0.8	3.25	10.71	4.92	7.21	2.280	5.01	14.42	4.79	2.750	2.750	1.750	9.39	3.800	4.150	7.33	4.500	4.800	4.800
1.0	3.36	10.48	4.78	7.42	2.570	5.17	14.10	4.61	3.040	3.040	1.750	9.14	4.300	4.600	7.14	5.140	5.400	5.400
1.2	3.46	10.20	4.66	7.61	2.860	5.30	13.85	4.50	3.330	3.330	1.750	8.94	4.800	5.100	6.99	5.720	6.000	6.000
1.4	3.54	10.20	4.57	7.77	3.140	5.49	13.66	4.40	3.620	3.620	1.750	8.79	5.370	5.680	6.86	6.280	6.500	6.500
1.6	3.61	10.01	4.49	7.92	3.420	5.51	13.49	4.32	3.910	3.910	1.750	8.66	5.840	6.170	6.76	6.840	7.000	7.000
1.8	3.68	9.90	4.43	8.05	3.690	5.68	13.35	4.25	4.140	4.140	1.750	8.55	6.300	6.650	6.66	7.380	7.500	7.500
2.0	3.74	9.81	4.37	8.28	3.960	5.76	13.22	4.20	4.400	4.400	1.750	8.45	6.760	7.120	6.60	7.840	8.000	8.000
2.2	3.79	9.81	4.32	8.47	4.230	5.85	13.06	4.15	4.680	4.680	1.750	8.37	7.210	7.590	6.54	8.340	8.500	8.500
2.4	3.84	9.72	4.28	8.58	4.470	5.96	12.92	4.10	4.950	4.950	1.750	8.30	7.640	8.040	6.48	8.840	9.000	9.000
2.6	3.89	9.64	4.24	8.67	4.720	5.96	12.85	4.06	5.230	5.230	1.750	8.25	8.060	8.490	6.43	9.340	9.500	9.500
2.8	3.94	9.57	4.20	8.76	4.970	5.96	12.78	3.99	5.510	5.510	1.750	8.17	8.480	8.930	6.38	9.840	10.000	10.000
3.0	3.98	9.51	4.17	8.82	5.210	6.01	12.63	3.96	5.790	5.790	1.750	8.12	8.900	9.370	6.34	10.340	10.500	10.500
3.5	4.07	9.37	4.10	8.82	5.840	6.14	12.63	3.92	6.425	6.425	1.750	8.00	9.600	10.080	6.25	10.840	11.000	11.000
4	4.15	9.26	4.04	8.98	6.470	6.26	12.51	3.86	7.080	7.080	1.750	7.91	10.340	10.970	6.18	11.340	11.500	11.500
5	4.20	9.08	3.96	9.26	7.050	6.46	12.31	3.77	7.680	7.680	1.750	7.84	11.040	11.740	6.10	11.840	12.000	12.000
10	4.65	8.70	3.76	9.95	13.435	7.97	11.79	3.54	13.880	13.880	1.750	7.43	22.030	23.020	5.80	20.870	21.870	21.870
$\infty$	6.00	7.73	3.28	12.83		9.17	10.69	3.06			1.750	6.00	9.13		5.16		7.13	
	110/3	110/6	15	175											120/3			
	1.335	1.006	1.503	1.754											1.670			

\* The other dimension coefficients are the same as for a single-phase transformer.

† Convenient round numbers.

‡ Corresponding exact numbers.

TABLE 5.

Three-core Three-phase Transformers with Minimum Cost-function.

Specific Cost Factor, $m$	Rectangular Bars					Circular Bars				
	Dimension Coefficients					Dimension Coefficients				
	$1/L_1 L_2$	$1/L_1 L_3$	$2/L_1 L_2$	$1/L_1 L_3$	Cost- function ( $m = 1$ )	$1/L_1 L_2$	$1/L_1 L_3$	$2/L_1 L_2$	$1/L_1 L_3$	Cost- function ( $m = 1$ )
0	2.17	24.04	9.22	4.54	1,229	3.41	28.52	9.14	1.304	
0.1	2.50	18.28	9.71	5.35	1,800	4.05	20.01	9.30	1.850	
0.2	2.85	15.78	5.77	5.05	2,190	4.31	19.23	5.68	2.250	
0.4	3.10	14.22	5.19	6.41	2,800	4.67	17.50	5.07	2.910	
0.6	3.28	13.43	4.80	6.76	3,370	4.91	16.60	4.72	3.500	
0.8	3.42	12.87	4.68	7.04	3,900	5.10	16.16	4.56	4.030	
1.0	3.54	12.48	4.53	7.28	4,400	5.26	15.76	4.41	4.520	
1.2	3.63	12.18	4.42	7.47	4,860	5.39	15.44	4.30	5.000	
1.4	3.72	11.94	4.33	7.64	5,310	5.50	15.20	4.21	5.470	
1.6	3.80	11.74	4.20	7.79	5,760	5.60	14.90	4.14	5.930	
1.8	3.86	11.58	4.20	7.93	6,200	5.70	14.80	4.07	6.370	
2.0	3.93	11.43	4.14	8.05	6,630	5.78	14.66	4.02	6.800	
2.2	3.98	11.30	4.09	8.17	7,060	5.86	14.53	3.97	7.220	
2.4	4.04	11.19	4.05	8.28	7,490	5.93	14.41	3.93	7.640	
2.6	4.09	11.09	4.02	8.37	7,910	6.00	14.30	3.89	8.060	
2.8	4.13	11.00	3.98	8.47	8,320	6.07	14.19	3.85	8.480	
3.0	4.17	10.92	3.95	8.55	8,730	6.12	14.11	3.82	8.900	
3.5	4.27	10.74	3.88	8.75	9,720	6.26	13.91	3.75	9.910	
4	4.36	10.59	3.83	8.92	10,700	6.38	13.76	3.70	10.880	
5	4.51	10.37	3.74	9.21	12,660	6.61	13.47	3.60	12.830	
10	4.80	9.97	3.60	9.80	22,020	7.34	12.76	3.35	22,210	
$\infty$	6.52	8.56	3.07	13.23	$\infty$	9.52	11.46	2.91	$\infty$	

TABLE 6.

#### Best Division of Copper between Concentric Coils.

Order- number	Perimeter Innermost Perimeter	As Circ Diagonals Max. Unit Density With Ideal Distribution	Concentric Coils		Subdivided Concentric Coils (1, 2, 3, 4)			Four Equal Concentric Coils				Extra Loss with Uniform Distribution compared with			
			$S_1 S_2$	$S_3$	$S_1/S_2$	$S_3$	$S_4$	$S_1 S_2$	$S_3$	$S_4$	Uniform in each of 2 Coils	Uniform in each of 3 Coils	Uniform in each of 4 Coils	Ideal Distri- bution	
			%	%	%	%	%	%	%	%	%	%	%	%	
0.1	1.1	95.3	48.8	51.2	24.1	50.0	25.0	24.1	24.7	25.3	25.0	0.06	0.06	0.07	0.08
0.2	1.2	91.2	47.7	52.3	23.3	50.0	26.7	23.3	24.4	25.6	26.7	0.21	0.24	0.27	0.28
0.3	1.3	87.5	46.7	53.3	22.6	49.9	28.5	22.6	24.1	26.0	27.5	0.43	0.48	0.54	0.58
0.4	1.4	84.8	45.8	54.2	21.9	49.9	30.2	21.9	23.0	26.0	28.2	0.71	0.79	0.88	0.94
0.5	1.5	81.1	44.9	55.1	21.3	49.7	32.0	21.3	23.6	26.1	29.0	1.03	1.15	1.28	1.36
0.6	1.6	78.2	44.1	55.9	20.8	49.6	33.8	20.8	23.3	26.3	29.6	1.37	1.54	1.71	1.83
0.7	1.7	75.2	43.4	56.6	20.3	49.5	35.2	20.3	23.1	26.4	30.2	1.74	1.97	2.10	2.23
0.8	1.8	72.5	42.7	57.3	19.8	49.4	36.8	19.8	22.9	26.5	30.8	2.13	2.41	2.68	2.86
0.9	1.9	71.3	42.0	58.0	19.3	49.4	38.3	19.3	22.7	26.7	31.3	2.53	2.86	3.20	3.41
1.0	2.0	69.3	41.4	58.6	18.9	49.3	39.8	18.9	22.5	26.8	31.8	2.95	3.33	3.71	3.98

## ELECTRIC GENERATING STATIONS IN CHINA.

By Professor C. A. MIDDLETON SMITH, M.Sc., Associate Member.

*(Paper read before the HONG-KONG LOCAL CENTRE, 23 March, 1915.)*

One of the objects underlying the foundation of this Local Centre was to supply information about electrical engineering in China to engineers in Great Britain. It is difficult to find any complete records about this subject, and a few general remarks may therefore be excusable, if only because people in Great Britain, generally, do not fully understand what is meant by a non-industrial country.

It is now some 12 years since the writer first became interested in engineering work in China. Three young Chinese students from Shanghai went to London, and in the course of their college training there were many opportunities to discuss with them the state of affairs in their native land. It is, perhaps, not a very difficult thing to train young Britishers to become engineers, because the Proceedings of every engineering institution team with papers and advice upon the subject. There is also a very general idea as to the probable destiny of most of the students. But when Chinese young men appeared the problem was a new one. What was to be their career? What was it necessary for them to know?

After a time a number of Chinese students passed through the colleges and universities in which the author was employed, and, as is usual in such cases, after a time the professors and lecturers found it almost impossible to do anything else but to train the Chinese student in the same way as the British student. All of us, the author is quite sure, felt uncomfortable about the Oriental students, for it seemed obvious that what would be useful to a youth going to a works in Birmingham or Manchester was unsuitable for one going to China.

Having thought a good deal about the matter in London, it was a disappointment to find, on arrival in China, how hopelessly ignorant it is possible to remain on such an important and interesting matter as the condition of a country in which about 400 million people live. One did not expect to find Canton like London, nor Shanghai like Liverpool, but one did have the general impression that China was becoming like the kinetic West, and that a very large number of the Chinese were not only quite conversant with modern inventions, but were determined to introduce them into their own country, if indeed many of them had not already been introduced. But, as all of us resident in the Far East know quite well, we entered into an entirely new world when we took up our abode out here.

The first great surprise was to find that China is a country which, for practical purposes, is entirely devoid of roads. More than 90 per cent of the inhabitants are living under conditions which are the same as those which existed in China 2,000 years ago. It is quite probable that 90 per cent of the inhabitants of China have never heard of a steam engine, or of a heat engine of any description. They have certainly not seen or heard of a Pelton wheel or a water turbine.

Of those who have seen an engine the very great majority have only glanced at the locomotive or marine steam engine. It is idle to speculate about the number of Chinese who have any idea of what is meant by the words "electrical power station," but it surely cannot be one-tenth of one per cent of the population. Possibly about 10 per cent of the people have seen the ordinary electric lamp, and about one-tenth of that number have seen a gas lamp.

There are, for all practical purposes, only three methods of communication in China in which the work of the engineer is employed. These are: (1) steamer traffic on the coast and up four or five rivers; (2) railways, the total length of which is now about equal to the mileage in Japan; (3) telegraphs, which are under Government control and seem to be operated fairly successfully.

## HONG-KONG AND SHANGHAI.

In the whole of China there are only three places in which modern industrialism is even attempted on any scale such as is common in towns of, say, 50,000 inhabitants in England. These places are Hong-Kong (a British colony), Shanghai (a foreign settlement), and Hankow. In these places the work of the electrical engineer is very much in evidence. Object lessons hundreds of miles apart are thus provided for the Chinese, and it is only fair to add that these object lessons are viewed with great interest.

The engineer who visits Hong-Kong and Shanghai notices a very great contrast. The two outstanding features in Hong-Kong are the public works—especially the waterworks and the good roads—and the three large dockyards. In Shanghai the distinguishing features are the enterprising electricity-supply system and the numerous factories, such as cotton mills, etc. Shanghai has good roads, but the conditions there are much kinder than those in Hong-Kong, for the settlement is very flat, while the colony has a series of roads cut out of the face of the granite rock which forms the island. There are shipyards in Shanghai, but they are not so large as those in Hong-Kong. In the latter place, the Hong-Kong and Whampoa Dock Company, the Taikoo Dockyard and Engineering Company, and the Royal Naval Dockyard probably employ about 600 European managers, engineers, foremen, etc., and about 7,000 Chinese workmen of various grades.

These three dockyards are well equipped with all modern machine tools, many of which are motor-driven in accordance with the most improved modern practice. In the Taikoo Dockyard there is a large central power station containing 1,000-h.p. gas engines and continuous-current generators with a total capacity of 2,250 kw. Mond gas producers supply the fuel for the engines, but it should be mentioned that most of the coal used in Hong-Kong is brought from Japan. It is understood that the Hong-

Kong and Whampoa Dock Company will abandon its steam-driven central station, which has a capacity of 500 kw., and will take a bulk supply of electrical energy from the local supply company. The Dock Company has on order and will this year install two 6-phase rotary converters (60 cycle) of 350-kw. capacity each. Current will be supplied from the China Light and Power Company's Hungghom power station. In the Naval Dockyard there is a central station with steam and Diesel engines.

In the colony of Hong-Kong there are two public electricity-supply companies. That which is on the island and supplies the city of Victoria has a station containing 2,000 kw. of Diesel engines and 600 kw. of steam engines, and it is an open secret that a new steam turbine-driven station is being planned. The existing station seems to have been placed in a most unsuitable site (it is on a ledge of rock some distance from the sea and about 100 feet above sea-level), and although originally a steam-engine station, it now employs Diesel engines. The present price of electrical energy as supplied by this company is 24 cents a unit for lighting and  $7\frac{1}{2}$  cents for power, with a recent concession of 5 cents for power during certain hours. For the purposes of comparison in this paper the cent will be taken at  $\frac{1}{4}$ d., and this means that the consumer in the city of Victoria, Hong-Kong, pays 6d. for lighting and  $1\frac{3}{4}$ d. and  $1\frac{1}{4}$ d. for power at this date.

There is also a separate generating station for supplying power to the tramways. This is steam-driven, and probably will disappear in time. The Hong-Kong University has its own central station, installed largely for educational work, with a total capacity of rather over 100 h.p. of gas, oil, and steam engines, a steam turbine, and a Pelton wheel. There are perhaps half-a-dozen smaller generating plants in the colony, mostly driven by gas engines with suction-gas producers. Although coal gas is used for heating and lighting, the only engine in the colony using coal gas (other than those at work in the local gas works) is a 15-b.h.p. Crossley engine installed in the University power station. With this engine the fuel costs about 9 cents (2 $\frac{1}{4}$ d.) per electrical unit generated.

In Kowloon, on the mainland portion of the colony of Hong-Kong, the China Light and Power Company supply light and power. Their plant is rated at 516 kw., but 1,500 kw. is to be installed this year.

Near Hong-Kong (about 45 miles away) there is the Canton Electric Supply Company. It must be remembered that Canton is the most populous, and is usually regarded as the most progressive, city in China. There are well over a million inhabitants. The Canton Supply Company uses steam and Diesel engines—it was originally a steam-engine station—and its total capacity is 1,540 kw. It is the general impression that the Canton engineers found it difficult to cope with the rapidly growing load. There seems to be no doubt whatever that the Chinese shopkeeper, and especially the Chinese restaurant keeper, are willing to pay high prices for electric light, and they use it in the most lavish fashion.

About 18 months ago a most progressive Chinese, Mr. Kwok Yik Ting, discussed at great length with the author the problem of electricity supply in Canton, and but for the sudden and untimely death of Mr. Kwok there would probably have been formulated by this time a comprehensive scheme for the extension of electricity

supply in Canton. It is to be sincerely hoped that the present directors will go forward with some of the ideas of Mr. Kwok.

It may be mentioned, for the benefit of those who have not visited Canton, that practically all the connections with the supply station are by means of overhead lines.

Near Canton—about 12 miles away—there is a supply station at Fatshan. It seems a pity that arrangements could not be made to supply power in bulk to many of the so-called villages in the neighbourhood of Canton. Of course one must remember the unsettled state of the country in that district, but Chinese robbers and thieves, despite their great liking for copper in any shape or form, seem to have a wholesome dread of touching transmission lines.

In the delta of the Canton river there is the small Portuguese settlement of Macao, which has its own electric supply plant.

#### THE YANGTSE VALLEY.

The great centre of electrical development in China is Shanghai, and any British engineer who has visited the Far East must be immediately impressed by the remarkable progress made in the International Settlement. It is at once conceded that the conditions are more favourable in Shanghai than in any other place in the Far East for such enterprise, but at the same time many opportunities have been seized there which might easily have been lost.

The Shanghai generating station compares most favourably with anything of its kind in Europe or America. It is, indeed, a model for the Far East, and British engineers should be very proud of the fact that it has been built up under the direct personal supervision of a Britisher. It is a tonic for any engineering pessimist to visit the place.

The station is steam-driven with two 5,000-kw. and two 2,000-kw. turbines. It is favourably situated at the side of the river. All the latest mechanical coal-handling devices, etc., are employed. The station has been carefully planned for large extensions. To give some idea of the scale, it may be mentioned that quite recently the chief engineer has suggested some extensions which amount to 20,000 kw. It will be the biggest extension so far attempted there, and it is likely to cost something like £200,000, including all the step-up and step-down transformers, underground cables, etc. Mention must be made of the industrial development of Hankow and of other places in the valley of the Yangtse-Kiang River. It is almost certain that this region will be the first part of China to develop works and factories on a large scale, but it must not be forgotten that the Cantonese have, among the Chinese, the greatest reputation for enterprise and business instincts.

#### COMMERCIAL PROSPECTS.

Information has been collected concerning the electrical business done by British and other firms in China, and although this is not complete, yet some general indications of development will be gathered from the following facts.

An English firm have installed 102 steam engines in China, with a total rating of 28,960 b.h.p. Most of these are used for electricity supply. This firm publish an

interesting map of China showing about 40 places in the country where these engines are to be seen. None of the engines seem to be larger than 500 b.h.p., and the average size is 284 b.h.p.

Another British firm have installed in North China at Soochow city in Kiangsu Province a 375-kw. 3-phase alternator direct-coupled to a high-speed steam engine, complete with high-tension switchboard, etc. The above British-made plant was supplied as an extension to the original, which was of German origin. In Chang Chow in Kiangsu Province there is a 150-kw. 3-phase alternator direct-coupled to a high-speed steam engine complete with water-tube boilers, high-tension switchboard, transformers, etc. The above was a new installation. In Tientsin there are two 75-kw. continuous-current generators coupled to high-speed steam engines, supplied for extension lighting of the Japanese settlement. Further contracts recently secured are for the lighting of two other large Chinese cities; the electrical plant consists of one 200-kw. and one 150-kw. 3-phase alternator. A large number of single-phase and 3-phase motors from 5 up to 100 h.p. have also been supplied for use in cotton mills and other factories. Amongst other installations are the equipment of several river and coasting steamers with electric light plants, consisting of continuous-current generators of about 20-kw. capacity, direct-coupled to high-speed vertical steam engines. This firm says that an outlet for electrical plant is comprised in up-country hospitals, missions, and private Chinese residences where small dynamos driven by oil engines are very much in favour. In South China they have supplied a plant to Fatshan, Kwangtung Province; there are three 60-kw. 3-phase alternators, with direct-coupled exciters, belt-driven by three 90-h.p. crude-oil engines, and a high-tension marble switchboard consisting of 14 panels. This installation is probably unique in South China, as the three machines are arranged to run in parallel and do so perfectly satisfactorily, although driven by ordinary crude-oil engines. In Shek Ki there are two 30-kw. 200-volt continuous-current generators driven by suction-gas engines. Many small steam engines and dynamos for lighting river steamers have been sent to South China, and various steamers as well as small oil-driven sets for hotels and private houses.

A merchant firm state that they have supplied various electric lighting installations in South China as follows: For the Canton Government one 60-kw. 250-volt continuous-current dynamo belt-driven by a 125-b.h.p. twin-cylinder horizontal gas engine, with suction-gas plant. This set was not erected at the Canton Yamen, but was transferred to the Nanking Exhibition. At Shek Ki, Heungshan, one 30-kw. 220-volt continuous-current dynamo belt-driven by a 66-b.h.p. suction-gas engine. At Cheung Chow one 8-kw. 220-volt continuous-current dynamo belt-driven by a 14-b.h.p. suction-gas engine. At Kongmoon, Kwangtung, one 40-kw. 2,000-volt, 60-cycle single-phase alternator, belt-driven by a gas engine. At Hoihow, Hainan, one 21-kw. 220-volt continuous-current dynamo belt-driven by a 45-b.h.p. horizontal crude-oil engine. This firm have also installed a large number of small private plants, consisting of horizontal and vertical kerosene oil engines, driving by belts or direct-coupled to 100-volt continuous-current dynamos, ranging

from 1 kw. to 10 kw.; also one 12-kw. 100-volt continuous-current set direct-coupled to a vertical semi-Diesel engine at Tung Shan, Canton.

A large European firm of electrical engineers have supplied the following more important plants in the South: One 140-kw. Diesel single-phase 2,200-volt alternator for the Canton Electric Supply Company. They have also recently received an order for a 750-kw. Diesel alternator from the same Company. They have supplied, or are at present supplying, the Macao Electric Light Company with four Diesel engine-driven alternators, each for 3,000 volts 3-phase, 200 kw. They have supplied in Yunnan two water-turbine sets, each of 300-kw. capacity, the pressure being 3,000 volts, stepped up to 23,000 volts, and the length of transmission line 25 miles. Besides the above they have supplied several private and small plants to and around Hong-Kong and Canton. In the North they claim to have supplied the bulk of the large plants, especially in such places as Pekin, Changsha, the Nanyang Iron Works, Tsingtau, Pinghsing Collieries, and so on; all these plants are large turbo-alternators, some of 1,000 kw. and others much larger.

A number of other British firms have sent engines and dynamos to China, and quite a number of oil engines and suction-gas plants are at work.

#### WORKING COSTS IN CHINA.

In the case of the new installations the general practice at present seems to show that the Chinese commence on a scale of rather under 100 kw. There is probably not very much difference in the cost of running crude-oil engines and suction-gas plants of this size.

Take a small oil-engine installation of 50 kw. The capital cost of the engines, foundations, dynamos, and switchboard would be (roughly) \$13,000 (£1,300). A rough building and land would probably bring it up to \$15,000 (£1,500).

We find at the University that crude oil can be used as fuel to cost less than  $2\frac{1}{2}$  cents ( $\frac{1}{2}$ d.) per unit; lubricating oil, and waste, etc., say  $\frac{1}{2}$  cent ( $\frac{1}{4}$ d.) per unit. Wages for supervision, drivers, etc., \$200 (£20) a month, say \$2,400 (£240) per annum.

The output of the station is reckoned at 50,000 units per annum. The cost of depreciation per annum is 10 per cent, say \$1,500 (£150). The total cost of depreciation, wages, etc., is, say, \$4,000 (£400) per annum, or 8 cents (2d.) per unit. The running expenses are 3 cents ( $\frac{3}{4}$ d.) a unit. Hence the total generating costs are about 11 cents ( $2\frac{1}{2}$ d.) per unit. As overhead mains may be used, the distribution costs are low.

Experience has shown that Chinese will pay 25 cents ( $6\frac{1}{2}$ d.) a unit, and there is clearly a very good margin of profit.

At the present time there seem to be all sorts of sporadic efforts to supply light from small stations. British, American, German and other kinds of machinery are to be seen. There is practically no legislation in China concerning electric supply, and if progress continues as at present, there will be endless annoyance and confusion for engineers and customers in a few years. It seems necessary to map out the populous country in South China into areas, put in say a dozen small oil- or gas-driven stations in each area, all uniform and under the general supervision of one

European engineer. In the course of time these would be linked up with a large turbine-driven station and the buildings used as sub-stations.

If water power is used it is probable that, even with long transmission wires, a company would make big profits if it sold energy at 8 cents (2d.) a unit.

#### GENERAL CONCLUSIONS.

After two years of study of the subject, the author has the impression that at present the demand for electrical apparatus in China is on a comparatively small scale. Shanghai is the one great exception. Commercial men in Britain might possibly be pessimistic about the outlook as they read these figures, but there are two or three factors to be remembered which may make them take a rather more rosy view of the future prospects in China.

(1) There is a great desire among all classes of the Chinese to have electric light, and experience in and around Hong-Kong seems to prove that they are quite willing to pay for it at even extravagant prices.

(2) The plants already installed are having an educational effect. In nearly all cases extensions are contemplated.

(3) The Chinese are particularly anxious to make use of applied science; during the last few years the shrewd business men in the coast ports have been repeating vaguely, but sincerely, "There is money in it." It is to be hoped that the Chinese will not blindly adopt all things European, but it is almost certain that they will extend greatly the use of electricity. A responsibility rests with Europeans in the Treaty Ports to educate them in this work. Thousands of Chinese are turned away in Canton and other cities from popular lectures on "Electric Lighting." Can we imagine tens of thousands of Londoners going to the Albert Hall to listen to a lecture on such a subject?

(4) The simple statement that, of the 167 students in the Hong-Kong University, 92 have selected engineering as a profession, shows quite clearly the direction of the thoughts of the more progressive parents.

(5) Twenty-five years ago most of the supply stations in Great Britain were installing units of about the size of those now being used in China.

Up till the present there has been practically nothing in the nature of an educative campaign on behalf of electrical machinery in China. This Local Centre might reasonably be expected to do its utmost to further electrical science in the Far East. There are difficulties, financial and administrative, to be overcome before this market is greatly increased, but the greatest difficulty of all is to provide object lessons to the Chinese, and to supply information and unbiased advice. In the furtherance of that work the Engineering Department of the Hong-Kong University will be happy to do its utmost, as we feel that it will be greatly to the advantage of China if the quantity of electrical apparatus sent out here is increased.

It is always very dangerous to attempt to forecast the future, but it would seem that the outlook is particularly good. The large numbers of Chinese students who are now being trained in engineering work will explain to their countrymen what is common practice in other countries; they will educate and influence many people to use electricity, and they will explain to their friends and relatives that money is to be made by initiating supply

schemes. Many of them should be able to find employment as agents, shall we say technical compradores, or later on, partners with European firms in the East. They should be able to secure orders where Europeans cannot obtain an entrée.

The large oil companies are busily extending their market all over China. Possibly the immediate developments inland will be brought about by the use of oil engines or water turbines. The use of coal inland is not probable even in the immediate future. Even in South China it is necessary to use Japanese coal, and the price seems to be about \$10 (£1) per ton. The fuel problem is one that will be solved easily, when the Chinese begin properly to develop their own natural resources. At present it is serious, but it does seem to be a fact that the Chinese are willing to pay for electric lighting, and so the price of fuel is not so vital as at first might seem to be the case. The electrical engineer has to compete only with such crude illuminants as the candle and oil lamp.

The question of standardization of supply systems is much too large a matter to be dealt with in this paper, but it might well form the subject of a contribution to this Local Centre later on. At present Hong-Kong has a single-phase supply system at 75 cycles, while Kowloon, just across the water, is able to supply 6-phase 60-cycle motors. Is it too much to hope that some effort will be made to obtain some uniformity in order that salesmen of electrical goods may not have to keep many stocks of the same article? It would be ideal if Hong-Kong, Kowloon, Canton, Macao and other places in South China used the same alternating- or continuous-current systems. There seems to be a danger that in the development of electricity supply there will be many troubles arising out of sporadic efforts. This Local Centre might use its influence to warn capitalists and engineers of the unfortunate experiences in the industrial parts of Great Britain owing to the multiplicity of supply systems.

#### APPENDIX.

##### BRITISH ELECTRICAL TRADE WITH CHINA.

During the month of December 1914 the value of the electrical goods exported to China and Siam from Great Britain was £5,383. Similar exports to Hong-Kong were valued at £1,296. The Straits Settlements, Malay States, and Sarawak took electrical goods worth £8,037. In the same month Japan and Korea imported £41,437 worth, and India £58,813. India and the Far East received £107,499 worth of electrical goods out of the total of such exports from Great Britain valued at £519,549.

For about the first half of the year 1914, the average monthly values of electrical exports from Great Britain were :—

Europe ... ..	88,000
India ... ..	78,000
Australia ... ..	74,000
British South Africa... ..	45,000
Argentina ... ..	45,000
Japan ... ..	38,000
Canada ... ..	36,000
China, Hong-Kong and Malay States	27,000
New Zealand... ..	23,000
Brazil ... ..	23,000

The author has evidence that engineering goods exported from Britain to Japan are re-exported from Japan to China.

It should be noticed that India is a remarkably good customer for the British electrical manufacturer. It

possesses the great advantage of stable government, but so far as the development of natural resources is considered, it does not seem to possess the possibilities of China as a market for electrical goods.

### DISCUSSION.

Mr. E. T. WILLIAMS: Those who have lived for a number of years in China and have taken the trouble to study its inhabitants, realize that it contains enormous potentialities. The very vastness of the country and its population account for its slow awakening to Western progress; but a time comes—probably the period we are now passing through—when there is a renaissance and rapid progress may be predicted. Not long ago Western education was largely despised; surely we must read into the author's statement that thousands were turned away from a lecture in Canton on "Electric Lighting," that this lethargic state of the past is departing. To my mind the most important part of the paper is contained under the heading of "General Conclusions." I have repeatedly advocated in the electrical Press and elsewhere that without co-operation Great Britain cannot hope to create and reap the possibilities of electrical work in a vast country like China. We welcome various evidences of co-operative publicity work, etc., but they are only one step. If this prospective market is to be really exploited, what is wanted is co-operation embracing the selling of machinery, the undertaking of contracts, and the devising and financing of electrical schemes; in other words, employ in China methods adapted to the circumstances of the country. The electrical and engineering firms of Great Britain should combine their resources for China, and then, having studied the possibilities, should have sufficient faith to distribute throughout the country a properly organized and constituted business network, largely composed of educated Chinese engineers under European control. This organization should conduct in China the business of the united British interests. In time it would become a self-supporting organization and would create a great demand for the electrical manufactures of Great Britain.

Mr. F. GRAHAM: The author mentions that in this part of the world the practice appears to have been to start electric light stations with steam engines and later to change to Diesel or gas engines. In my own case (Hong-Kong Electric Company) the reason is obvious, as we did not have sufficient water for condensing. Apart from that, in the case of small sets Diesel engines or gas engines are cheaper to run than steam engines, though not so reliable; whereas in the case of larger plants, steam turbines are able to compete in regard to fuel cost, and the cost of maintenance is much less. I am surprised to hear that a pressure of 23,000 volts is being used for transmission at Yunnanfu; it is very encouraging, and I should be interested to know whether the transmission is under European supervision or not. The author mentions a 50-kw. installation, and gives the cost of supervision, wages, etc., as \$200 (£20) per month; I presume, therefore, that the supervision is only Chinese. The depreciation allowance of 10 per cent is, I consider, correct; it should certainly not be less, as a station starting with 50-kw. sets would find in all probability that in 10 years' time a 50-kw. set would be

too small for practical use and would have to be scrapped. Mr. Overhead mains certainly reduce the cost of distribution; but if used for main feeders in coast ports which may be visited by typhoons they do not conduce to continuity of supply. The author seems to consider the prices of electrical energy in Hong-Kong extravagant, but I would remind him that 5d. is still a common price in England, and that supervision, plant, and materials cost more out here, and also that our graded scale of discounts to consumers whose accounts exceed \$25 (£2.5) a month causes the cost of the unit to vary from 0.24 cent (0.06d.) to 0.16 cent (0.04d.) according to the amount consumed.

Mr. D. W. MUNTON: I should like to make a few remarks from a contractor's point of view. On page 165 of the paper the author mentions that it is the endeavour of the Hong-Kong University to supply Chinese customers with unbiased advice; this of course refers to the purchasing of machinery or to the preparation of schemes for electric lighting or power transmission. Too much stress cannot be laid on this point. At present the usual method in vogue in Hong-Kong and the Treaty Ports is somewhat as follows:—Assuming that some Chinese comes down from the interior to purchase machinery, he is generally discovered by the various compradores, into whose clutches he falls, and, as each of these have axes to grind, the unfortunate customer is taken from one contracting firm to another. Not one, but several estimates are submitted in the course of negotiations extending over a week or more, and disastrous competition follows, the final result of which is that, in order to be in the running, the very minimum of machinery is offered, together with a vaguely worded tender. When the contract is finally awarded, the firm in question generally begins to consider what items not absolutely indispensable can be cut out. One of the first things omitted by unscrupulous firms is an adequate system of excess pressure and lightning dischargers. Usually nothing at all is supplied, or at best a simple, horn gap, with the horns so far apart that it is impossible for them to operate. Many other items can be omitted if sufficient ingenuity is displayed. In order to show to what extent some firms will go, I will quote a case. In the North of China I saw a plant supplying a rather important area with current at 2,200 volts. The switchboard consisted of a teak board, with a single-pole knife switch and a voltmeter; the fuse was a piece of copper strip which was never intended to "blow." Unfortunately, contractors of repute here have to compete with firms who sell anything from tinctaks to aeroplanes; and some of these firms, having very little in the way of reputation to live up to, promise anything and seldom fulfil their promises. They offer absurd deliveries, and then when these fall due it is extraordinary the number of *force majeure* accidents that take place, such as fires at the works, the stranding or delaying of ships, or strikes. The author has it in his power to alter this to some extent—and thus to terminate

this disgraceful state of affairs—by instilling thoroughly into his students the necessity of differentiating between quality and quantity. In connection with my previous remarks about lightning arresters, I would here point out how necessary such apparatus is; for during a thunderstorm the arresters at Yunnan have been known to discharge as often as 40 times in an hour, and these are heavy discharges. The plant generates current at 3,000 volts, 3-phase, and the pressure is raised to 23,000 volts; a drop of some 3,000 volts is allowed along the line, and in Yunnan the pressure is about 20,000 volts. One of the conditions of the contract was that the plant was to be erected by Yunnanese labour, and since initially there were no artisans in that district, the first task was to teach these men. The plant is under European supervision.

Mr. W. L. CARTER: With reference to the author's statement that "China is a non-industrial country," the making of homespuns on cottage looms is just as much an industry as that carried on in the large mills of Leeds and Bradford. Nor is it true that industrially the country is unorganized. China is the cradle of trade unionism, and the guilds have held complete control for many centuries. It is, I think, due to the great efficiency of these guilds that this people have resisted, more successfully than did British workpeople, the introduction of modern methods into their ancient industries. Small power plants will continue, in my opinion, to be purchased by individuals; but before any large schemes can come to fruition the whole question of security for both foreign and native capital will have to be satisfactorily settled. Concerning the direction of specification, even at home and in America it is difficult to decide the direction in which a student should specialize, and it is easy to understand how much more this applies to the young engineers being trained in Hong-Kong University. I would hand on to the engineering students the advice given to me by my late professor, namely, that they are at college to learn how to continue to educate themselves during the whole period of their careers. On page 163 of the paper the author says that Chinese robbers and thieves, despite their great liking for copper in any shape or form, seem to have a wholesome dread of touching transmission lines. I wish that this were true, as the protection of overhead copper lines outside the cities is regarded by most of us as a very great difficulty. The ability of the Chinese to maintain the supply systems themselves will surely prove a most important factor in the progress of the electrical industry in this country, and in this connection I would draw attention to a remark on page 165 where the author seems to think that the supervision of a European engineer will always be necessary. I am inclined to disagree with him, and to think that the University will very soon be able to supply men of the calibre of the engineers of Japan. It is really only a question of the attitude of mind. On the question of standardization, I consider that for the present no encouragement should be given to the Chinese bureaucracy for exercising their talent for drawing up endless and ridiculous regulations; but nevertheless this Local Centre should certainly proceed to develop its views upon the subject.

Professor T. H. MATTHEWMAN: On pages 164 and 165 the author conveys the impression that the Chinese are willing to pay extravagantly for electricity used for lighting pur-

poses. I think this opinion must be formed from local conditions, and then only from a certain type of consumer, namely, the restaurant keeper or the wealthy inhabitant. Surely if electricity is to appeal to the majority of China's millions, it will be from the standpoint of its economy as compared with existing illuminants. I consider this to be the vital point in a country such as China where the scale of living is so low. I should like to bear out what the author says about the importance of the engineering graduate as a factor in the development of the electrical industry here in China. Such graduates will be in a position to spread abroad the advantages of electricity among their fellow-countrymen, and will also be fitted to urge upon buyers of electrical machinery the need for proper supervision—a point often neglected, with the result that a bad reputation is obtained for electricity as an illuminant and as a means of conveying power. While connected with a Government institution in Shanghai I received through students numerous inquiries from up-country people about electrical plant. Some of those inquiries afterwards materialized into small installations, with the student graduate in charge. The American manufacturer has realized the importance of training such graduates, and at least 12 leave the above-mentioned institution yearly to pass through the workshops under advantageous conditions, and afterwards come back to China to represent these firms and push American goods. If British manufacturers would offer similar conditions, I think it would be greatly to their advantage in the future. I quite agree with what Mr. Williams says about standardization. It is a most important subject, and this Local Centre should make it one of its chief objects to co-operate with the engineering societies in other parts, so that regulations can be got out for China in official quarters, in order to prevent such confusion and unnecessary expense as is illustrated in this paper.

Mr. G. E. MARLEY: I should like to emphasize the great need in Hong-Kong and China generally for the unbiased consulting engineer. Unless buyers of machinery seek advice from men of known integrity and with no business interests in any particular firm, they will certainly not obtain the best results when they introduce machinery into their country. I have a great opinion of the ability of the Cantonese mechanics, who seem to possess real engineering instincts.

Professor SMITH (in reply): I think that, for the immediate future, European supervision of generating plants is necessary; but when Chinese graduates have sufficient experience they should be able to run the plants by themselves. In Britain expert advice is frequently needed, and just at present the only experts in China are Europeans. I think that the suggestion to do without meters and to charge a fixed amount per annum a good one, but the difficulty seems to be in connection with the time for switching on and off. In Japan, where water power is used, there is a system of monthly charges per lamp, and it is quite common to see electric light left on in broad daylight. The word "non-industrial" was perhaps not very happily chosen; "undeveloped" would be a better word. I quite agree with Mr. Williams concerning co-operation, and should like to mention that the British Electrical and Allied Manufacturers' Association have guaranteed the electrical

Professor  
Matthew  
man.

Mr. Marley.

Professor  
Smith.

equipment for the Hong-Kong University — a most excellent example of co-operation. With regard to the prices of electrical energy in Hong-Kong, I am glad to hear of the discounts for large consumers. I could not obtain details of the frequencies of the various

alternating-current systems, but I hope they will be obtained by the Local Centre. In conclusion, it is true that various local merchants sell electrical accessories, but of course it is essential that trained engineers should carry on that class of work.

## POLE-FACE LOSSES.

By F. W. CARTER, M.A., Member.

(Paper received 9 December, 1915.)

### INTRODUCTORY.

The subject of eddy-current loss in the pole-shoes of dynamo-electric machines, due to the passage of opposing teeth, is not susceptible to ready experimental investigation; for the loss in question is always accompanied by others from which it is not easily separated, some being of greater magnitude than that sought, and functions of the same variables, whilst others are uncertain and depend on circumstances over which little control is possible. The matter is therefore one in which a computed result, if derived in general accordance with the physical conditions, affords more secure ground for confidence than a test result. Even if this were not so, however, the calculation is still a natural preliminary to the test, indicating the general manner in which the several variables are involved, and leaving it to the test to take account of residual effects and special circumstances not covered by the assumptions of the calculation. Some years ago\* the author gave the appropriate formula for the eddy-current loss in solid pole-shoes, without giving, however, the calculation by means of which it had been derived. Inasmuch as this formula has recently been mentioned† and the question raised as to exactly what it represents, it seems desirable that the complete calculation should be published.

### VARIATION OF POLE-FACE FLUX-DENSITY.

The variation in pole-face flux-density due to the existence of armature teeth was discussed in the paper referred to above, and constituted, in fact, the sole reason for introducing the formula. In a particular case, for which the field of force about the slot is shown in Fig. 1, the variation in pole-face density is shown in Fig. 2. In general, if  $s$  is the breadth of the slot, and  $g$  the length of the gap measured over the tooth, the flux density at the pole-face varies from a maximum value  $B$ , over the crown of the tooth, to a minimum value  $B_1/\sqrt{[1+s^2/4g^2]}$  over the centre of the slot. The total variation is accordingly

$$B_1 \left\{ 1 - \frac{1}{\sqrt{[1+s^2/4g^2]}} \right\}.$$

The variation of flux density does not follow any simple law, but being periodic, with the tooth pitch as period, and having the general characteristics shown in Fig. 2, the

assumption that the variation follows a sine law is not a great departure from the physical facts. Accordingly, if  $B'$  is the amplitude of the variation, assumed sinusoidal,

$$B = \frac{1}{2} B_1 \left\{ 1 - \frac{1}{\sqrt{[1+s^2/4g^2]}} \right\}$$

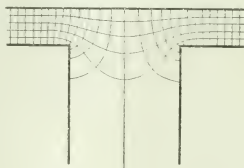


FIG. 1.—Magnetic Field near Slot.

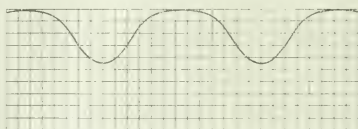


FIG. 2.—Flux Density at Pole-face.

The known flux density is, however, not  $B$ , the maximum, but  $B_1/k$  the mean, where  $k$  is the air-gap coefficient.\* Calling this quantity  $B$ , the amplitude  $B'$  is given by

$$B = \frac{1}{2} B_1 \left\{ 1 - \frac{1}{\sqrt{[1+s^2/4g^2]}} \right\} \dots (1)$$

\* *Electrical World and Engineer*, vol. 38, p. 885, 1901.

† *Journal I.E.E.*, vol. 54, p. 75, 1916.

\* For curves giving  $k$ , see *Electrical World and Engineer*, vol. 38, Fig. 6, 1901; also *Journal I.E.E.*, vol. 34, p. 48, Fig. E, 1905.

## FUNDAMENTAL EQUATIONS.

Since the tooth pitch is small compared with the radius of the pole-face, the curvature of the latter may be neglected. Let the plane of the pole-face be taken as that of  $xy$ , and let the axis of  $z$  be drawn inward to the pole. Let the axis of  $x$  be parallel to the slots. Let  $u, v, w$ , be the components of current density parallel to the axes, and  $a, b, c$ , the components of flux density in these directions. Let  $\mu$  be the permeability, assumed constant, of the iron in the neighbourhood of the pole-face, and  $\rho$  its specific resistance. The fundamental equations of the field are\*

$$\frac{db}{dz} - \frac{dv}{dz} + 4\pi\mu u = 0 \quad (2)$$

$$\frac{dc}{dx} - \frac{dw}{dz} + 4\pi\mu v = 0 \quad (3)$$

$$\frac{da}{dz} - \frac{dw}{dx} + 4\pi\mu w = 0 \quad (4)$$

$$\frac{dv}{dz} - \frac{dw}{dx} - \frac{1}{\rho} \frac{da}{dt} = 0 \quad (5)$$

$$\frac{dw}{dx} - \frac{du}{dz} - \frac{1}{\rho} \frac{db}{dt} = 0 \quad (6)$$

$$\frac{du}{dx} - \frac{dv}{dz} - \frac{1}{\rho} \frac{dc}{dt} = 0 \quad (7)$$

From these equations it follows that any one of the six quantities  $u, v, w, a, b, c$ , is derivable from an equation of the form

$$\nabla^2 u = \frac{4\pi\mu}{\rho} \frac{du}{dt} \quad (8)$$

## CASE OF SOLID POLE-SHOES.

In this case, the axial length of the pole being considerable as compared with the tooth pitch, the solution may be assumed independent of  $x$ ; moreover, if  $q$  is the tooth pitch and  $V$  the velocity of the teeth over the pole-face, the sine law of variation of the applied flux density leads to a solution varying as  $e^{2\pi i(y-Vt)/q}$ . Thus Equation (8) reduces to the form

$$\frac{d^2 u}{dz^2} - \left( \frac{4\pi^2}{q^2} - \frac{8\pi^2\mu V}{q\rho} \right) u = 0 \quad (9)$$

The appropriate solution of this varies as  $e^{-\lambda z}$ ,

$$\text{where } \lambda = \frac{4\pi}{q^2} - \frac{8\pi^2\mu V}{q\rho} i,$$

$$\text{or } \lambda = \frac{2\pi}{q} \sqrt{(\sec 2\alpha) e^{-i\phi}} \quad (10)$$

$$\text{where } \tan 2\alpha = 2\mu V q / \rho \quad (11)$$

Thus

$$u = u_0 e^{-\frac{2\pi}{q} \sqrt{1 + \frac{2\mu V q}{\rho} \cos \alpha} z} e^{\frac{2\pi}{q} \sqrt{1 + \frac{2\mu V q}{\rho} \sin \alpha} V t} \quad (12)$$

Similarly, with  $v, w, a, b$ , and  $c$ . Now the component current at right angles to the pole-face is zero at this face, ( $w=0$ , when  $z=0$ ); accordingly  $w_0=0$  and  $w=0$  throughout. Hence, from Equation (4),  $a=0$  throughout,

and from Equation (3) or (5),  $v=0$  throughout. Equations (6) and (7) give

$$\frac{u}{2\pi V t q} = \frac{b}{a\lambda} = \frac{c}{2\pi a q} \quad (13)$$

The eddy-current loss of power is

$$W_1 = \frac{1}{2} \rho \iint u^2 dxdydz \quad (14)$$

the integral being taken throughout the pole. The mean loss per unit area of pole-face is accordingly

$$\begin{aligned} W &= \frac{1}{2} \rho \int_0^\infty u_0^2 e^{-\frac{1}{q} \sqrt{1 + \frac{2\mu V q}{\rho} \cos \alpha} z} dz \\ &= 8\pi \sqrt{(\sec 2\alpha) \cos \alpha} \quad (15) \end{aligned}$$

It remains now to determine the relation between  $u_0$ , which determines the amplitude of the eddy current, and  $B'$  [Equation (1)] the amplitude of the field causing this current; actually  $B'$  is, in this case, sensibly equal to  $e_0$ , and  $u_0$  is given by Equation (13), for the field due to the eddy current is small; it is, however, desirable to show this and to determine the relation between  $B'$  and  $u_0$  in order that the results may have as wide an application as possible.

The flux density at ( $y, 0$ ) perpendicular to the pole-face and due to the element of current at ( $yz$ ) is

$$dc = \frac{4\mu}{\mu+1} \cdot \frac{y'-y}{z^2 + (y'-y)^2} u dy dz,$$

hence

$$\begin{aligned} c &= \frac{4\mu}{\mu+1} \iint \left( \frac{y'-y}{z^2 + (y'-y)^2} \right) e^{-\lambda' z} e^{2\pi i(y-Vt)/q} dy dz \\ &= \frac{4\mu}{\mu+1} e^{2\pi i(y'-Vt)/q} \iint \left( \frac{y'-y}{z^2 + (y'-y)^2} \right) e^{-\lambda' z} e^{2\pi i(y-y')/q} dy dz, \end{aligned}$$

the integral being extended throughout the pole.

Now for a particular value of  $z^2$

$$\int_0^\infty \left( \frac{y'-y}{z^2 + (y-y')^2} \right) e^{-\lambda' z} dy = \pi i e^{-2\pi i y'/q}$$

$$\text{hence } c' = \frac{4\mu}{\mu+1} \pi i e^{2\pi i(y'-Vt)/q} \int_0^\infty e^{-(\lambda + 2\pi i/q)z} dz$$

$$= \frac{4\mu}{\mu+1} \cdot \frac{\pi i}{\lambda + 2\pi i/q} e^{2\pi i(y'-Vt)/q} \quad (16)$$

Thus at the pole-face see [Equation (13)],

$$\begin{aligned} c - c' &= \left\{ -\frac{\rho}{V} + \frac{4\mu}{\mu+1} \cdot \frac{\pi i}{\lambda + 2\pi i/q} \right\} u e^{2\pi i(y-Vt)/q} \\ &= -\frac{\rho}{V} \left\{ 1 + \frac{\lambda - 2\pi i/q}{2\pi(\mu+1)q} \right\} u e^{2\pi i(y-Vt)/q} \quad (17) \end{aligned}$$

The modulus of  $c - c'$  is  $B'$ ; substituting the value of  $\lambda$  from Equation (10) accordingly,

$$u_0^2 = (B')^2 \frac{V^2}{\rho^2} (\mu+1)^2 / [\mu^2 + 2\mu \sqrt{(\sec 2\alpha) \cos \alpha} + \sec 2\alpha] \quad (18)$$

\* See MAXWELL'S "Treatise on Electricity and Magnetism," vol. 2, chapters 8 and 9; or J. J. THOMSON'S "Elements of Electricity and Magnetism," chapter 11.

\* See TOHMYSTER'S "Treatise on the Integral Calculus," chapter 12, § 293.

Hence from Equation (15),

$$W = \frac{q V^2 (B')^2}{8 \pi \mu \sqrt{(\sec 2a) \cos a}} \cdot \frac{(\mu + 1)^2}{\mu + 2 \mu \sqrt{(\sec 2a) \cos a} + \sec 2a} \quad (19)$$

This is the general formula for the power loss per unit area of pole-face; in the case considered, however,  $\mu$  is of the order of  $10^3$ ,  $V$  is several times  $10^3$ ,  $\rho$  is about  $10^4$ , and  $q$  is a few units, hence in Equation (11)  $\tan 2a$  is large and  $a$  is nearly  $\frac{1}{2}\pi$ ; thus  $\sec 2a = \tan 2a$  and  $\cos a = 1/\sqrt{2}$  approximately. The second fraction in Equation (19) becomes practically unity, and

$$W = \frac{q V^2 (B')^2}{8 \pi \mu \sqrt{(\mu V q / \rho)}} \\ = \frac{1}{8 \pi} q^{\frac{1}{2}} V^{\frac{3}{2}} \rho^{-\frac{1}{2}} \mu^{-\frac{1}{2}} (B')^2 \quad (20)$$

This is the formula in absolute units corresponding to that to which reference has been made.

#### CASE OF TANGENTIALLY LAMINATED POLE-SHOES.

Here the tooth pitch is great compared with the thickness of the laminations, and it is sufficient for the purpose in view to assume the eddy-current density to have a component parallel to the  $y$  axis and of value

$$v = \frac{2 \pi V t}{q \rho} B \lambda e^{-\lambda x} \cos \pi i V t / l \quad (21)$$

the other components being zero; in this equation  $x$  applies only to a single lamination and is measured from its centre. The value of  $\lambda$  is now

$$\lambda = 2 \pi \sqrt{\left(\frac{\mu V}{q \rho}\right) (1-i)} \quad (22)$$

The eddy-current loss per unit area of pole-face is,  $h$  being the thickness of a lamination,

$$W = \frac{\rho}{h} \int_0^{\infty} \int_{-h/2}^{h/2} v^2 dx dz \\ = \frac{\rho}{2h} \cdot \frac{4 \pi^2 V^2}{q^2 \mu^2} B'^2 \int_0^{\infty} \int_{-h/2}^{h/2} \lambda^2 e^{-4 \lambda x} \cos^2 \pi i V t / l dx dz \\ = \frac{\rho}{2h} \cdot \frac{4 \pi^2 V^2}{q^2 \mu^2} (B')^2 \frac{h^3}{12} \cdot \frac{1}{4 \pi} \sqrt{\left(\frac{q \rho}{\mu V}\right)} \\ = \frac{\pi}{24} h^2 q^{-\frac{1}{2}} V^{\frac{3}{2}} \rho^{-\frac{1}{2}} \mu^{-\frac{1}{2}} (B')^2 \quad (23)$$

This is the appropriate formula for the laminated pole-shoe. Comparing the results of Equations (20) and (23) it will be seen that the ratio of the eddy-current losses in lami-

nated and solid pole-shoes is  $\frac{1}{2} \pi^2 (h/q)^2$ . Actually this ratio should be increased somewhat, since the flux density in the iron is greater in Equation (23) on account of the poorer space factor of the laminations; the actual ratio of these losses, with  $B'$  given by Equation (1), is approximately  $(2 h/q)^2$ .

#### HYSTERESIS LOSS.

In the case of the laminated pole-shoe the hysteresis loss is likely to form an appreciable fraction of the whole. If the law of loss indicated by Ball's investigation\* be assumed, the appropriate pole-face loss is readily obtained. According to this the loss per unit volume per cycle is given by

$$H = (q + \eta' B^{1/\eta}) (B')^{1/\eta}$$

where  $B$  is the mean flux,  $B'$  the amplitude of the variation, and  $\eta$  and  $\eta'$  constants. The hysteresis loss of power per unit area of pole-face is accordingly

$$W' = [q + \eta' B^{1/\eta}] \frac{V}{q} (B')^{1/\eta} \int_0^{2\pi} e^{-3/2 \pi \sqrt{\lambda}} \cos^2 \pi i V t / l d\tau \\ = \frac{1}{3/2 \pi} q^{-1} V^{\frac{3}{2}} \rho^{\frac{1}{2}} \mu^{-\frac{1}{2}} (\eta + \eta' B^{1/\eta}) (B')^{1/\eta} \quad (24)$$

#### APPENDIX.

##### NOTATION EMPLOYED.

$x, y, z$  = co-ordinates in space.

$u, v, w$  = components of current density.

$a, b, c$  = components of flux density.

$c'$  = component flux density due to eddy currents.

$W$  = mean power loss per unit area of pole-face.

$B$  = mean air-gap density.

$B'$  = amplitude of oscillation in air-gap density at pole-face [Equation (1)].

$\mu$  = permeability of iron near pole-face.

$\rho$  = specific resistance of iron of pole-shoe.

$h$  = air-gap coefficient.

$g$  = air-gap, iron to iron.

$s$  = slot width.

$q$  = slot or tooth pitch.

$V$  = velocity of slots over pole-face.

$a$  = see Equation (11).

$\lambda$  = see Equations (10) and (22).

$\eta$  and  $\eta'$  = hysteric constants.

$i$  = imaginary operator.

J. D. BALL. "The Unsymmetrical Hysteresis Loop." *Proceedings of the American Institute of Electrical Engineers*, vol. 34, p. 2275, 1915.

## DISCUSSION ON

## "SOME DIFFICULTIES OF DESIGN OF HIGH-SPEED GENERATORS."

BIRMINGHAM LOCAL SECTION, 24 NOVEMBER, 1915.

Mr. T. H. HURST: One of the most interesting features in the paper is the magnetic wedge. The many advantages of such a wedge are obvious. About five years ago a lot of time was spent on the design of a wedge to be used in a similar way on machines smaller than that which is the subject of this paper. The problem presented many difficulties, the chief of which was to compromise mechanical design with iron losses, and those, too, in a part of the machine where the maximum heat was generated. In view of the fact that the wedge illustrated has been already used, a statement of the approximate value of the iron losses in it would be of great interest. The rotor wedge (Fig. 5) appears to present a difficulty from the point of view of being driven home. On the assumption that the central part is one piece the full length of the core, the side wedges, which are of small section, are apt to swell during driving; or, if in short pieces, a large amount of driving on a small surface, and depending on the length of the core, is necessary before they are in position. The herring-bone clamps on the stator winding shown in Fig. 9 may be satisfactory from a mechanical point of view, but introduce a serious difficulty with regard to the insulation between the top and bottom layers. I assume this design was used on the machines mentioned on page 73, which were insulated for 30,000 volts. The small apparent clearance between the top and bottom layers and the difficulties of insulation constitute a grave objection to this design. In consequence of the manufacture of large generators, the time seems to have come when higher temperature-rises than 40 and 45 degrees C. should be called for in specifications by consulting engineers. As the speed of 24,000 feet per minute is and has been a maximum for the last five years, the area of the air inlet into the rotor is fixed. An air velocity of 6,000 feet per minute is also a maximum. Consequently any increase in the size of generators, which is the present tendency, will simply mean a rotor lengthened to suit, a slightly smaller amount of air, and therefore a slight increase in the temperature-rise corresponding to the increased output of a machine already up to the above limits. Many machines in different countries have been made where the temperature-rise of the copper embedded in the rotor slots is over 100 degrees C. and the insulation gives complete satisfaction. In such circumstances, it is only common sense and true economy of material to raise the present standard temperature-rise in this country to one of the order of about 70 degrees C. Such a figure would enable manufacturers in this country to compete more favourably with Continental makers.

Mr. R. J. KAULA: It is rather surprising to note that the designs shown in the paper have not involved a higher journal speed than 100 feet per second. In supplying bearings for a smaller set, having an output

of 3,000 kw. at 3,600 r.p.m., or about 4,500 k.v.a. maximum continuous rating, we have gone as high as 110 feet per second, but this high speed has not affected the satisfactory running of the bearings in any way. I fail to understand why the author attaches such importance to running below the first critical speed, and it would be interesting to know his reasons for doing so. I think it is quite common practice in this country to run generators between the first and second critical speeds, but to ensure that the running speed is well removed from the critical speeds. I should like to know whether the Westinghouse Company have used solid couplings for connecting these large generators to their turbines, or whether they use flexible couplings in all cases. We have found the solid type of coupling very satisfactory on smaller units. It is interesting to note that the author recommends the use of separate fans for ventilating purposes, instead of fans mounted on the rotor. A number of machines are running in this country where separate fans have been installed, but to the best of my knowledge the ventilation provided by these fans is supplementary to that produced by the rotor. I am inclined to think that the separate fan system presents considerable advantages, more particularly as it is very difficult to obtain an efficient fan which, when mounted on a rotor, is limited in dimensions and speed by considerations quite extraneous to its proper design. I regret that the author has given up the use of the ton as a unit, apparently as the result of his stay in the United States.

Mr. B. A. M. BOYCE: The paper does not cover the ground suggested by the title, as it is practically a study of one machine. A reference to some of the difficulties of high-speed continuous-current generators would have been an advantage, as with the sizes of machines generally made in this country, the difficulties are greater with continuous-current than with alternating-current machines. I agree with the author that the critical speed of turbo-alternators should be well above the running speed. With regard to ventilation, axial ventilation where the air has not to turn sharp corners is in my opinion the best where it can be used, but in a machine of the size described it is obviously not enough. We build machines up to 3,500 kw. with simple axial ventilation (i.e. a 7,000-kw. set with the Ljungstrom type of turbine, as there are two alternators in parallel to each set). With regard to the single-phase generator, it is not clear whether there are dampers in the pole-face as well as in the wound portion of the rotor; if there are not, I should like to ask the author if he has had any trouble with the slip-rings and brushes. We find that we can get perfect results on medium-size single-phase generators by means of copper wedges entirely round the rotor, and special bronze end-caps to which the wedges are connected by a properly designed joint, and that it is an advantage to make the wedges in the pole-face of

Mr. Higgs copper and steel, so that the effective air-gap is not reduced. The stator-slot magnetic wedge described is very interesting.

Mr. J. M. WALSHE: It is well known that the transverse tensile strength of a rolled plate is less than the longitudinal tensile strength. Moreover, "piping" in the ingot will cause a bad streak or lamination in the plate; and boiler plates so affected have failed under quite moderate loads. I should like to know whether any special test is made on the rotor plates by which faults of this description can be detected. Ordinary transverse tensile and bending pieces are at best merely local and only give local indications, not disclosing the presence of these very fatal faults in other places.

Mr. H. W. TAYLOR: The author has discussed the design of a 20,000-k.v.a. turbo-alternator running at 1,800 r.p.m. This design contains certain unusual features, especially as regards rotor construction. In the past, in their search for the paths of progress, designers have evolved machines with features which at the time were considered unusual and even revolutionary, and although the machines themselves have been satisfactory in that they have maintained the supply of power on their respective circuits for some years without serious intermission, yet when later types of machines are examined it is found that certain of the features of these earlier ones have, for reasons both commercial and technical, not persisted. It is difficult to say exactly what one's own difficulties would have been at the time and under the circumstances that the present problem was originally presented to the author, and therefore it is difficult to discuss the results with reference to its original setting, especially as we gather that several of these machines have been built and are presumably performing satisfactory service. In this connection, however, one regrets that for the benefit of both designers and consulting engineers, he has not included characteristic curves whereby the performance of the machine may be judged. I think, however, one may profitably discuss the matter from a more general standpoint and consider whether the design is one that will continue to recommend itself. Such a discussion, although it might be in some measure destructive as regards the particular design, would be constructive as regards the progress of the art of design of these machines as a class. The author starts his description of his machine rather axiomatically by saying: "There is first the problem of constructing a rotor which must necessarily weigh something of the order of 60,000 lb., and which will be running with a peripheral speed in the neighbourhood of 24,000 feet per minute." I venture to think, however, that when the author first turned this matter over in his mind, the primary consideration which presented itself to him was not as just stated, but the question of critical speed discussed later in the paper. The critical speed and the various attendant phenomena which follow one another in rapid succession as the shaft runs through this speed, provide a very interesting study, and the dangers exemplified in the simple cases discussed in the text-book have taken a strong hold on the minds of engineers. At an early date certain designers—notably De Laval and Parsons—conceived that the phenomenon of critical speed should not be allowed to limit every other feature in their designs, and sought means

to obviate its dangers, with the result that at the present time there are many machines in satisfactory service which are running above their critical speed, and which pass through this speed on running up and shutting down, without that fact being apparent to their attendants. The effect of this question of critical speed has resulted, as the author remarks, in a design of rotor with a large diameter, and a previous speaker has called attention to some undesirable features which have resulted. It may be further pointed out that for the reason that the active belt cannot be very usefully employed, the output is not as great as one would expect to obtain from a machine of this size and speed; and further, that the restrictions imposed by mechanical considerations provide difficulties at a later stage when short-circuit problems are considered. Experience on this point was so unfortunate with some of the early types of machines that the feeling still continues that the modern turbo-alternator is still liable to give trouble to a marked degree. The danger of short-circuit may be said to be inversely proportional to the rapidly and ease with which the main flux of the machine can be suppressed. Now for a given speed the output is proportional to the product of the armature reaction and the flux, and, if we were to choose these factors with reference to the short-circuit condition, one would choose the armature reaction high because it is the means whereby the flux is destroyed, and the flux low, so that there is less of it to be dispersed. Unfortunately it would appear that the author has already tied his hands in this matter when he chose his dimensions as the result of the critical-speed question, for throughout the paper we see by his figures that his centrifugal stresses are so high that as shown by his illustrations he was restricted in the amount of copper which he could put into the active belt of the rotor. As a result his armature reaction has had to be relatively low and his flux relatively high, as confirmed by the statement at the bottom of page 74. Considering the relation of armature reaction and flux more from a designer's point of view, I think that generally speaking, of two machines, that will be cheaper which can carry the larger armature reaction and the smaller flux, because from the point of view of material alone a large armature reaction means an increased amount of copper only in the active belts of the stator and rotor, while a larger flux means an increased section throughout the whole of the magnetic circuit. Apart from the present design I should like to make a remark with regard to eddy currents produced in stator conductors on load. The author's discussion of this point is of course based on the theoretical treatment in his classical paper of 1905, and a study of this paper with reference to high-speed generators will indicate that a limit is soon reached in the width of the active belt on the stator if eddy currents are to be avoided. The conclusions in the original paper are theoretically correct, as has been proved by experiments with models, but in practice it would seem that the conditions in the high-speed machine with large pole-pitch are not exactly the same as those existing in the theoretical consideration, with the result that the eddy currents, although they do exist, are not present to the same amount, so that depths of conductors greater than those mentioned by the author can be adopted without the necessity of using elaborate crossings.

Mr. H. W. Taylor.

<sup>1</sup> Mr. A. M. TAYLOR: The author has stated on page 74 that while a certain amount of external reactance has its uses, it is also felt that these large machines should be so built as to stand a "dead" short-circuit at their terminals. I do not find any fault with the latter part of this statement, in fact it rather supports the contention which I have previously put forward, viz. that a certain amount of external reactance is desirable between the machine and the busbars in those cases where a large number of alternators are connected in parallel. The argument for the external reactance is briefly that there is a possibility of a short-circuit occurring in the end windings of the stator in such a position as to cut out a large proportion of the reactance of the stator; consequently, if the machine is connected directly with the busbars to which many other machines are connected, the current from these busbars into the short-circuit will be many times that which would flow into a short-circuit at the machine terminals if fed merely by the machine itself. Hence a short-circuit test of the machine after erection, which could only be made under the latter conditions, would be no criterion as to what would happen under the former conditions; in this case such forces might be set up in a part of the winding of the alternator as to wreck the end connections. Probably the best combination of internal and external reactances is that which permits the machine to be short-circuited on itself when on test without the external reactance, the latter then being so designed as to pass, in the event of a short-circuit occurring in the machine and near its terminals, only the same current from the busbars as the machine had been previously tested with. I think it will be conceded that it is undoubtedly easier to insulate the turns of the reactance, which are not cramped for room, than the end coils of the stator which are not only cramped for room but have to be bent and twisted about. With single-phase, paper-insulated cables and reactance coils of sound design, there ought to be practically no possibility whatever of a short-circuit exterior to the windings of the alternator; and no risk, even in those windings, which has not already been courted when the alternator was tested under short-circuit. I believe that, in the larger sizes of alternators, the limit at which it is commercially profitable not to introduce (internal) reactance is reached sooner than in smaller machines. It would be interesting if the author felt free to give the limit of size for, say, the introduction of  $7\frac{1}{2}$  per cent (internal) reactance, together with a statement as to the frequency, number of poles, and lowest power factor with which the machine is intended to be used.

Mr. F. W. CARTER: As a side issue I should like to ask the author whether he has ever experienced trouble from end thrust in the type of generator considered. With the usual flexible coupling between turbine and generator there is apt to be a tendency for the generator to be pushed with considerable force towards one end. This tendency may be balanced against a magnetic centering force,<sup>2</sup> but this sometimes leads to local heating, from the undue crowding of flux in some of the end punchings of the stator. I believe the proper remedy to lie in attention to the correct design of the coupling

<sup>1</sup> See *Minutes of Proceedings of the Institution of Civil Engineers*, vol. 187, page 311, for a calculation of the force and a discussion of the conditions favouring strong centering.

which is undoubtedly the source of the end thrust. The author refers\* to a formula of mine giving the pole-face losses, and appears in doubt as to what it represents. I may say that it is the result of a direct calculation starting with Maxwell's equations and carried through on orthodox lines. I consider therefore that it represents very closely the actual loss under the assumed conditions and I myself would trust it in preference to any empirical formula; for experiments designed to separate out such a loss as this are by no means easy, and are not likely to yield very consistent or reliable results. However, since the author has raised the point, I propose to prepare a paper† showing how the formula was derived: such a paper may also be of assistance in the experimental investigation of the subject.

Mr. E. K. SCOTT: I should like the author to give some figures regarding the maximum sizes of alternators which can be safely built with our present knowledge of the art. The design of these super steam turbo-alternators is of very special interest to this country, because by boldly installing them we shall be more than able to hold our own against countries which have large water-powers, and our position will be greatly strengthened in the electrochemical and metallurgical industries, which hitherto have been neglected. I notice that the peripheral speed of the alternator described by the author is about 24,000 feet per minute, which appears to be about the limit for a rotor carrying windings in slots. It may be of interest to note that nickel steel can be run safely at 35,000 feet per minute, this being the peripheral speed of the  $3\frac{1}{2}$ -ft. diameter gyro-wheels used on the Brennan monorail car. Of course, such a speed cannot be used where the rotor has slots and windings, but the question may well be raised whether it is not opportune to consider the inductor type of alternator which has no slots or windings in the rotor. Although such machines are heavy and have poor regulation their robust character is always in their favour, and many are still running which have not cost a penny since they were installed. Furthermore, it is now generally recognized that there are advantages in designing large alternators with poor regulation. Where the cross-section has to be much decreased by deep slots, the flux densities have necessarily to be very high, and this means very high quality steel from the magnetic point of view, although such steel is not necessarily of great strength. By doing away with slots in the rotor the steel need not be of high magnetic quality, and although more would be required the inductor would be much cheaper to build. In this connection it would be interesting to know the flux densities in the various parts of the magnetic circuit of the alternator described, especially the densities in the teeth of the rotor and stator. As alternators become larger the cooling of the same is more difficult because the ratio between the area of the outer surface and the energy losses becomes smaller. It has occurred to me that the cooling could be effected efficiently by allowing jets of air under pressure to flow into the machine, for example into the stator casing, so as to pass through the core and also impinge against the windings. Great cold can be attained in this way, as is shown by the exhaust ports of a compressed-air coal-cutter, which are usually covered with snow. Another way which the author says has been tried

\* Page 75.

† See page 118.

Mr. Scott. is to moisten the air passing through the alternator, with the specific object of taking advantage of the rapid absorption of heat by the latent heat of steam. This is not so good as the use of compressed air because of the danger of introducing moisture.

Mr. Clough. (Mr. F. H. CLOUGH also took part in the discussion. The substance of his remarks is given on page 77 in the discussion before the Institution.)

Professor A. B. FIELD (in reply): Mr. Hurst has asked for further information with regard to the stator-slot wedge. A considerable amount of care and time was bestowed upon the design of this wedge, to ensure a mechanically good structure and minimum power losses without great manufacturing difficulties. For instance, bare punchings are used, the tubular rivets are carefully located to avoid loss and so that bare tube may safely be used instead of insulated. A few of these wedges were tested in a separate apparatus arranged to provide the maximum cross flux corresponding to the machine conditions. No attempt was made actually to measure the watts loss, since the extremely low power-factors involved would have rendered the result of doubtful value; but temperature tests without the air blast which obtains in the actual machine indicated that the losses must be quite small. The total core loss of the complete machine, compared with similar narrow-slot machines, gave no indication at all of the magnitude of wedge losses, being lower than anticipated without allowance for wedge losses. The laminated wedge as a whole was insulated from the machine core by thin strips of hard fibre, avoiding one of the difficulties pointed out by Mr. Hurst. The use of such a wedge becomes feasible and advantageous for a comparatively large machine on account of the saving in cost resulting in other directions; but, personally, I should hesitate to use the construction on a machine with an output of a few thousand kilowatts, although I understand that this procedure has since been followed to some extent. With regard to the rotor wedge, Mr. Hurst anticipated difficulty in driving this into place. In the case of machines for balanced load, both the bronze and the steel components are in comparatively short lengths and the difficulty does not arise. For the machines designed for unbalanced load, the central copper section is in a single piece and the steel liners in short lengths. The comparison that we must consider, therefore, is that of driving the long, single-piece copper wedge over the coil while the coil pressure is acting upon it, versus slipping in the long, single-piece wedge and then driving the short, hard steel, side strips into place with the radial coil pressure relieved by external screws. The short steel strips are introduced from each end of the rotor. Previous experience with the first process had indicated the objections to it, and led to the method described. Regarding stator coil bracing, the difficulties of insulation mentioned by Mr. Hurst undoubtedly arise and have to be met. Mica channels were used in these machines to reinforce the insulation where the metallic grids occurred. The distance between the two layers of winding was sufficient for a substantial grid. I entirely agree with Mr. Hurst as to the necessity of allowing higher temperature rises than 45 degrees C. for the rotor copper (if measured by resistance); but the question must be considered closely in conjunction with that of the insulating material used.

In answer to Mr. Kaula, the couplings used for these machines are not what I judge he means by solid couplings, although the degree of flexibility is extremely slight. The cases mentioned by this speaker in which separate fans are used in this country are somewhat different from those in which this arrangement was advocated in the paper. For small machines where fans can be reasonably incorporated in the machine itself, I should be in favour of the self-contained machine; but in large units conditions favour the other arrangement. As to the use of the ton as a unit, I would simply draw attention to the ambiguity arising with this unit, inasmuch as it nearly always signifies in the States 2,000 lb. instead of 2,240 lb.

Mr. Boyce rightly draws attention to the large field of problems in connection with high-speed continuous-current generators; but the paper only purported to refer to some difficulties of design, and was submitted as an introduction to discussion, with the hope of bringing forward many other contributions such as Mr. Boyce could so advantageously give us in connection with difficulties of commutator design, etc. As to the single-phase rotors, I would say that dampers are located in the pole-face as well as in the wound portion, and this is certainly most important. Perhaps a little confusion has arisen in connection with Fig. 7, showing the 2-pole single-phase rotor, as the zone of the periphery immediately in view is that dividing the windings of the two poles and is not the polar surface. In Fig. 6 the front part of the rotor is the polar surface, the rotor being a 4-pole one.

In reply to Mr. Walshe, the method adopted for testing the plates was as follows:—(1) A longitudinal test-bar in a specified location was taken out of each plate at the mill, upon which acceptance or rejection was based. Upon receiving the plates at the factory about one out of each six had two further test-bars taken out of it, longitudinally and transversely. This supplemented close inspection.

Referring to the interesting remarks of Mr. H. W. Taylor, I would say that the actual problem presented itself to us after experience with the design and construction of cruciform solid rotors up to 10,000 kw.; of solid cylindrical rotors of both cast and forged material; of radial slot rotors using a through shaft and forged nickel steel discs, also a through shaft and punched steel discs, and other constructions. I think that undoubtedly the most prominent difficulty appearing at the time was that of getting material which was absolutely reliable, and this was looked upon as the first problem to be solved. An experimental machine of about 10,000-k.v.a. rating with a plate rotor had been constructed and tested with a view to solving the problem of material for the large units that were quite clearly going to be demanded. Reference has already been made, in reply to the London discussion,\* to the questions of critical speed, rotor size for output, and the relation between the armature reaction and the flux per pole. In particular, it has been pointed out that, contrary to Mr. Taylor's statement, the machine described is not a high-flux machine, in comparison with other large machines, so far as comparison is possible. A fair basis of comparison of different machines in the matter of armature reaction is obtained by giving the effective stator ampere-conductors per inch of periphery

at the bore. In case the stator coil-pitch is less than the pole-pitch, the effective number of ampere conductors per inch is obtained by multiplying the actual number by the cosine of half the (electrical) angle by which the coil-span lacks one pole-pitch. Using this basis, I find that the machine in question has over 50 per cent more ampere-conductors per inch than a large 60-cycle General Electric turbo-generator, and 20 per cent more than another large 25-cycle General Electric turbo-generator of which I happen to have approximate data. In each case the figures are based upon the maximum rating. My statement equally holds good in a comparison with other machines of which I have accurate data. It was hoped that the description and data given would have led to similarly generous information being released by other firms, and it would enhance the value of this discussion if Mr. Taylor or Mr. Clough would give tabulated data of recent successful large machines constructed by their firm in England or the United States. I should be most pleased to supply information with respect to the machines described, in order to complete such a tabulation of data to be published here, covering important recent machines of various makes. The tabulation should give complete rating, rotor dimensions and type, air-gap, stator connection, conductors per slot, slots per pole, and stator coil-pitch (whence the flux per pole follows approximately), the maximum possible short-circuit current, and other data. Referring to the precautions required with deep stator conductors, Mr. Taylor rightly points out that the assumptions made in the paper on "Eddy Currents" to which he refers are not strictly complied with in these machines; but my experience with large water-wheel and steam-turbine driven machines, quite irrespective of theoretical considerations, has forced me to be very careful in this respect, while keeping well in mind the mechanical aspects of the case also.

Mr. A. M. Taylor refers to the limits of size in which sufficient reactance can be embodied in the machine. A little ambiguity arises sometimes in referring to a certain percentage internal reactance in connection with momentary short-circuit problems. Doubtless an effective reactance is here meant, which is to be obtained by considering the experimentally-obtained maximum short-circuit current; but as the value of this maximum depends upon the phase of the voltage across the terminals at the instant of short-circuit, and as it is largest when the terminals are short-circuited at the instant of zero voltage, giving the first few oscillations of current nearly all on one side of the zero line, we should rightly refer to the internal reactance as being 5 per cent when it is such as to give us a maximum possible short-circuit current of, not 20 times the rated current, but 40 times. On this basis, Mr. Taylor's 7.5 per cent internal reactance would correspond to a maximum possible short-circuit current in the neighbourhood of 25 times the rated current, and I think that we can advantageously and economically keep down the short-circuit current to this limit or less in machines of sizes up to those here discussed.

Mr. Carter draws attention to the end thrust produced by certain types of flexible coupling. The degree of flexibility of the coupling used in these machines is very small, and the effect described has not come to my attention, nor am I aware that the stators have been purposely

erected with their centre lines displaced relatively to those of the rotors. Mr. Carter's promise to prepare a paper in connection with pole-face losses is very greatly to be welcomed. The formula given in his article on "Air-gap Induction" for such losses is as follows:—

$$\text{Watts per sq. in.} = 8 B^2 D n^2 \mu \times 10^{-10},$$

where  $B = k \frac{1}{2} \pi (4 + \pi b/g) \frac{1}{2} B$ ;

$B_m$  = mean air-gap induction in lines per sq. in.;

$k$  = equivalent, divided by the actual, gap length;

$b/g$  = ratio of slot width to gap;

$D$  = rotor diameter in inches;

$n$  = revolutions per minute;

$s$  = total number of slots in the circle;

and  $\mu$  = permeability.

The form in which I have used the result is given in the paper, and omits  $\mu$  and other constants. The difficulty that I have always anticipated in using the result numerically is on account of the uncertainty as to the value of  $\mu$  to be adopted. Picturing the conditions in the air-gap and for a minute distance into the pole-face, we find a varying magnetic density on the air-gap side of the pole-face. A small fraction of a centimetre inside the steel we have a uniform magnetic density, and the currents which are the immediate cause of the loss penetrate only a very small distance below the surface. The two magnetic flux distributions are made to harmonize with one another by a tangential path of the flux within the skin of the steel; consequently the effective value of  $\mu$  to be taken has always appeared to me to vary possibly from a quite low value for a small fraction of a millimetre at the surface to its normal large value at a distance within the steel at which the density becomes uniform. This subject is referred to again in reply to Dr. Cramp at the Manchester discussion.\*

In reply to Mr. Scott's remarks, I would say that the outputs mentioned in the paper have already been exceeded in the States by units of 25,000 k.v.a. at 1,800 r.p.m., 30,000 k.v.a. at 1,500 r.p.m. and 25 cycles, and 35,000 k.v.a. at 1,200 r.p.m. and 60 cycles; while I understand that 50,000 k.v.a. at 750 r.p.m. and 25 cycles has received serious consideration by manufacturers. The last-mentioned machine would appear entirely practicable from a design point of view. With regard to the limit of peripheral speed, this arises, in the case of the rotors discussed, more by considerations of the copper external to the cylindrical core than of slots and teeth in the body. The increased cost corresponding to a higher quality steel in the body of the rotor would not be excessive in the case of a plate rotor, but new means of supporting the overhanging copper would have to be sought, for any considerable increase in peripheral speed. Regarding the use of an inductor-type alternator for these large ratings, the abolition of windings from the rotating part is certainly an attractive feature, but the greatly increased size of the structure and consequent cost, apart from other considerations, are likely to prevent such a development. Referring to the flux densities in the stator teeth, these are limited rather by the figure at which undue flux is forced into the copper conductors in the slot than by other considerations. The rotor teeth which are encircled

Professor  
Field.

by the bulk of the winding become quite saturated. The cooling effect due to the expansion of compressed air which is noticeable in coal-cutters and similar apparatus, is one that is hardly likely to be made use of directly for cooling purposes in these machines, on account of the

comparatively large power expended for a small effect. In the cases mentioned by Mr. Scott, the parts exhibiting snow and frost are not the seats of loss, and consequently can be quickly brought down to the temperature of the issuing air.

Professor  
Field.

# MANCHESTER LOCAL SECTION, 30 NOVEMBER, 1915.

Professor  
Walker.

Professor M. WALKER: The construction of the steel body of the rotor described in the paper is very suitable where rotors of large diameter are required to run at high speeds, say at peripheral speeds of 24,000 ft. per minute. I gather from the paper that the author would recommend solid steel forgings where the peripheral speed is not too great to make these unsafe. For instance, on a rotor running at 1,500 r.p.m. and not measuring more than 50 inches in diameter, it would appear that satisfactory solid forgings can be obtained. The makers of these forgings are willing to guarantee satisfactory test-pieces taken from various parts of the forging in both a longitudinal and a tangential direction. As the present tendency is to

extremely satisfactory. The main points in its favour are:—(1) It supports the heavy end-windings in a thoroughly mechanical manner between stout steel cheeks; (2) the factor of safety can be made very much higher than where the windings are supported only by end-bells; (3) the copper in the rotor slots consists of deep bars so that there is very little insulation to give way; (4) proper provision can be made for the expansion and contraction due to the heating of the conductors; (5) the diameter of the rotor for a given output can be considerably reduced. To illustrate the advantages of this winding, Fig. B shows a lay-out of the end-connectors for a 50,000-k.v.a. generator running at 1,500 r.p.m. The diameter of the rotor is only

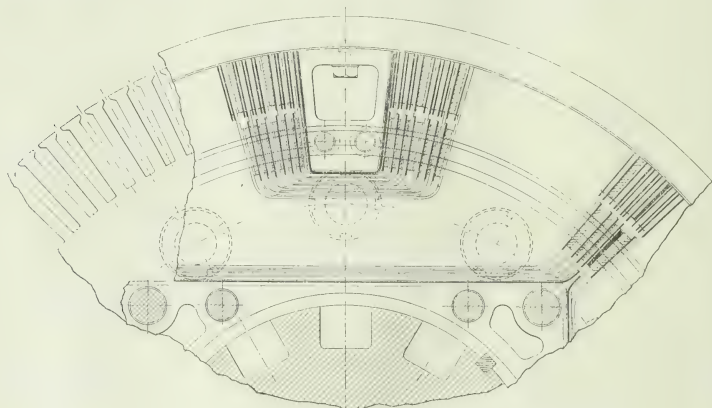
Professor  
Walker.

FIG. A.

build larger and still larger units, it is well that we have this steel-plate construction described in the paper, so that the peripheral speed can be still further increased without introducing an element of uncertainty. For small machines, and for machines of medium output, the separately-formed edgewise-wound coil shown in Fig. 8 of the paper has been found simple and convenient; but I believe that for the very much larger machines which are to be built in the future a better type of winding should be put forward. This type of winding, illustrated in Fig. A, is already in use in a large number of generators having a rating of 4,000 kw. and over, and has proved

58 in., so that the steel body can be built up with steel plates as described by the author, and the stresses would be less in it than in the 20,000-k.v.a. machine described in the paper. The main weight of the end-connectors is taken by the steel cheeks marked VV; the total stress in these cheeks due to the copper load and their own weight does not amount to more than 11,500 lb. per square inch. Owing to the method of clamping the cheeks shown in Fig. B, the through bolts shown in Fig. A can be entirely dispensed with. There are 88 slots and 6 bars per slot, each bar being skewed over through a distance of  $1\frac{1}{2}$  in. as it comes out of the slot, in order

to permit of expansion and contraction. It is found that owing to the extremely good ventilation of the parts of the bars which project from the slots, the copper section can be cut down to about one-half. This reduces the diameter and gives plenty of room for the steel hoops which support them. The total stress in these hoops is not more than 19,500 lb., and the factor of safety of the whole construction is a little over 6. The method of anchoring the hoops is shown in Fig. A. The electrical connection between the end-connector and the bar can be carried out by electric welding at the point W. The method of compressing the rotor coils while the wedge in the rotor slots is being fixed, as illustrated in Fig. 5, overcomes what has been a real difficulty. So far as the stator coils are concerned, I believe the plan of getting the coils a long way back from the rotor to be a very good one, and I propose

Mr. J. A. KUYSER: The author mentions a few of the difficulties encountered in axially ventilated machines where a large, central air duct is used for the air discharge. I should like to describe a system of ventilation which has recently been tried and which eliminates some of the objectionable features. The arrangement is illustrated in Fig. C, which shows a cross-section of an 8,000-k.v.a. 2,400-r.p.m. turbo-alternator. Axial vent chambers are provided in the usual way by means of holes punched in the core laminations. Nine radial air ducts each  $\frac{3}{4}$  in. wide are provided instead of one central duct. Each axial duct is therefore divided into 10 sections of equal length. These sections are connected together into a certain system by means of axial tubes which are welded to the ventilating spacers, the tubes serving at the same time to maintain the required distance

Mr. Kuyser

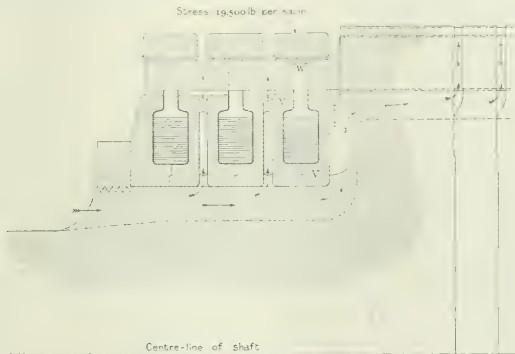


FIG. B.

to carry the idea very much further than the author shows. If the slots are made three or four inches deeper than at present, it is possible to get quite a wide space between the stator and rotor coils. This permits of sufficient leakage flux to cut down the stator current on short-circuit, and obviates the necessity of providing an expensive reactance coil, which causes a certain amount of loss. The extra depth of slot provides a good cooling surface which can be easily cleaned. Those who know how considerable are the copper losses in stator conductors owing to the stray flux from the rotor, will appreciate the advantage of getting the copper right away from the rotor. The general mechanical arrangement is very much preferable to the type of machine where everything is bunched down near the rotor with ventilation only behind. Here the ventilation is in front on the rotor side. I am quite sure this type will come to the front, particularly in very big machines. In conclusion I will only say that the paper has taken us forward many steps towards that great desideratum after the war—the cheap supply of electric power.

between the punchings. At certain places the connecting tubes are left out and semi-circular distance pieces are used, thereby allowing the air to escape from the axial ducts into the radial ducts. The air outlets are evenly distributed over the whole length of the core, an equal number of axial ducts delivering into each radial duct. Besides the elimination of the large central discharge, another advantage may be obtained by arranging the air streams in such a way that a counter-flow action is obtained. Looking at the outer circle of axial ducts in Fig. C, the air is admitted in a certain duct at the front end of the machine, passes through the whole length of the core, and is discharged in the last radial duct at the opposite end. The adjacent duct is supplied with cool air from the rear end and the air is discharged at the front end, the air streams in adjacent ducts thus having opposite directions, as indicated in Fig. C, where the full lines show the air streams in a cross-section through one slot, and the dotted lines the same in a section through an adjacent slot. That arrangement reduces the high temperature which occurs near the air outlet of axially ventilated machines, and it

Mr. Kuysser equalizes the temperature over the whole length of the core, as is shown by temperature measurements on machines ventilated in that way. In connection with the stator-coil bracing and the type of armature winding for turbo-generators, the diamond type of winding shown in Fig. 9 has been extensively used in the United States, and has been developed to a high state of perfection; some of the many improvements have been described by the author. In the diamond winding, the copper coils are formed completely on metal or wood formers, insulated and baked. When completely finished the coils are dropped into the open armature slots, and the magnetic wedges or fibre wedges are inserted on top of the coils. The bracing of the end connections, by means of the radial clamps shown in the figure, results in a very substantial and rigid construction. Small blocks of horn-beam, or similar insulating material, are roped between the straight parts of the coils which extend beyond the

be effected in a comparatively short time. Another type of winding, the concentric, has been largely used in this country and on the Continent. The concentric winding of a 5,500-k.v.a. 3,000-r.p.m. machine is illustrated in Fig. D. For large machines, the winding consists of separate bars and connectors, as shown. If only one conductor per slot is used, as is the case on that machine, the conductor must be split up into a number of parallel straps to avoid eddy-current losses. The required number of parallel straps and separate connectors can easily be determined by means of the author's well-known curves. The slot conductor is machine-wrapped with mica insulation, and pushed axially into semi-closed slots. The ends are then bent, and the individual connectors are electrically welded or sweated to the bars. The end connectors are braced by means of wood blocks and metal bolts, which clamp the connectors solidly together and against the end-plate. Heavy metal rings connect the ends of the bolts and pre-

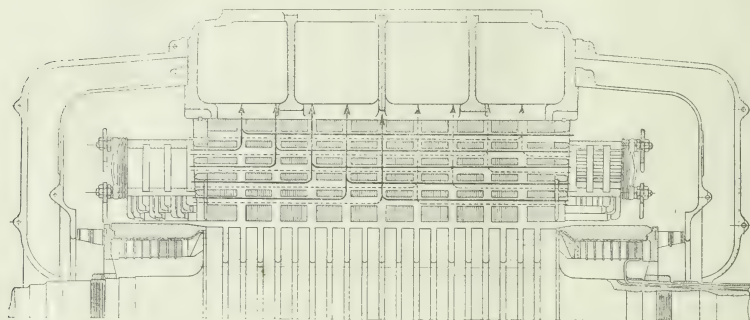


FIG. C.

core, and brace that part of the winding into a solid circle. The diamond winding is usually made with the number of coils equal to the number of slots, each slot receiving two coils. Fractional pitch can be used with advantage, especially on 2-pole machines. The fractional pitch has the advantages of greatly reducing the overhang of the winding, and of reducing the losses due to the stray field in the cast-iron parts of the armature. These losses are sometimes extremely high, especially if the concentric type of winding is used. The winding process of an armature in the shop requires comparatively little labour. The coils are simply dropped into the open slots and wedged in place. The coil braces are very easily fitted. For these reasons most shop engineers prefer that winding to the concentric type. A disadvantage of the diamond winding is the necessity for open slots, which introduce extra losses. If wide slots are used, magnetic wedges are absolutely essential. Another disadvantage is that several coils must be lifted out if a defective coil has to be replaced, which results in damage to the insulation of those coils. Against that it may be said that a complete rewind can

vent any bending. After a short-circuit it is often observed that the straight coil extensions have moved outward in a radial direction. To prevent this movement segmental pieces of fibre are inserted in the windings and form a support for the coils. The concentric winding has the advantage that each bar can be easily replaced without disturbance to the remainder of the winding. That advantage must not, however, be overrated, as a breakdown of the armature winding often starts a fire in the machine and necessitates a complete rewind. Other advantages which are specially appreciated by designers are the semi-closed slots and the absence of magnetic wedges. A disadvantage is the high local stray field around the end connections, which results in high eddy-current losses in the cast-iron parts of the armature. If both types of windings are considered on their merits, it is difficult to decide in favour of one or the other. Both types have their good points. Experience of a certain manufacturing concern and local conditions will therefore mainly determine the adoption of a particular type. With reference to rotor-coil bracing, the retardation shock due

Kuyser to a short-circuit, and the resulting deformation of the field coils, are not so severe as one would first expect. That may be shown by a short calculation. For example take a 15,000-k.v.a. 2-pole 1,500-r.p.m. machine. The data of that machine are as follows:—The rotor, consisting of a solid forging, has a diameter of 46 in. and a total weight of 22 tons. The torque developed on a short-circuit will be roughly 10 times the normal torque, or equivalent to 150,000 kw. This torque will produce a retardation equivalent to 15 times gravity on the diameter of the coils, which results in a force of 15 lb. on each pound of copper. The maximum deflection of the winding, which is made of copper of  $1\frac{3}{8}$  in. width, will be 0.015 in. If the flywheel of the turbine is taken into account, the deflection is only approximately 0.008 in. These figures seem to show that by using a substantially strong field strap the winding may be made sufficiently strong without

the ring even at full speed. The advantage of this method Mr. Kuyser. is that it avoids the keyway and leaves the rings of uniform section, which is important in view of the high stresses.

Mr. G. D. SEATON : I cannot discuss the design of high- Mr. Seaton speed generators, but I have had much unfortunate experience of their operation. On the 30th of last September I estimated that north of the Trent there was then no less than 68,000 kw. of high-speed generating machinery which had broken down. Immediately afterwards I found that the total was more like 80,000 kw. ; and a fortnight later I was informed by a competent authority on the subject that there was no less than 100,000 kw. out of commission in this country. Clearly it is time the matter were investigated. To my mind the curious feature is that the speed of the machines appears to have nothing whatever to do with the trouble ; in fact, the slower a machine the more liable to break down it appears to be. During the last three years

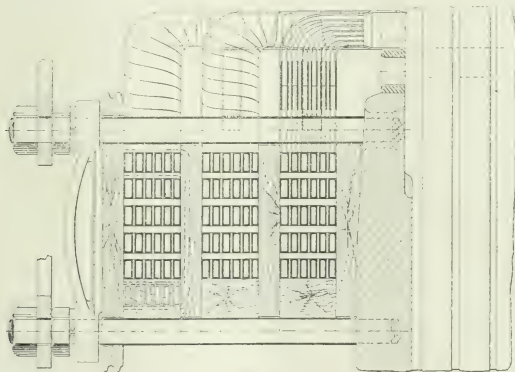


FIG. D.

extra bracing to withstand a short-circuit. The 15,000-kw. machine, to which these figures refer, has been repeatedly short-circuited on the test-floor without any apparent harm, although no bracing has been used. Three other identical machines are successfully operating as parts of the 30,000-kw. sets recently installed by the Interborough Rapid Transit Company of New York. A disadvantage of the bracing is that the ventilation of the end connections is partly obstructed. The temperature of the end connections is often the highest temperature of the rotor winding and the limiting feature of the design. Ventilation of this part of the winding is therefore very important. I agree with the author that means must be provided for driving the coil-retaining rings, in order to avoid a displacement or slipping of the coils on a short-circuit. As an alternative to the use of a key, the rings may be shrunk tightly on to the end-plates or on to the core. The shrink fit should be greater than the expansion in diameter due to the centrifugal forces, thereby ensuring a solid grip of

I have had only one instance of the breakdown of a rotor, a high-frequency single-phase machine ; almost all the trouble has occurred in the stators, and it will be very interesting to know if the author can throw any light upon the matter.

Mr. G. A. JUHLIN : As stated in the paper a through shaft Mr. Juhlin. would be out of the question in a machine of the diameter and speed referred to. Even in 50-cycle machines considerable difficulties would be encountered as regards stresses. The author mentions that stresses of 20,000 lb. may be expected inside the rotor, and the statement is probably rather under than over the mark. In order properly to secure the discs it is necessary to shrink them on, with shrinkage stresses considerably above the running stresses. A tight fit is required on the shaft when the rotor is running at its maximum speed ; otherwise the discs will be floating loose on the shaft, which, of course, is not permissible. Fortunately we are well situated in this country for obtaining steel forgings of large and small sizes, and

Mr. Jublin. for that reason it is probably unnecessary to adopt a disc construction until very extreme sizes are required. British steel-makers are prepared to supply rotors of very large sizes with excellent physical properties. The standard specification to which high-speed rotors are ordered is as follows:—

Ultimate tensile strength ...	80,000 lb. per sq. in.
Elastic limit ... ..	45,000 " "
Elongation, in 2 inches ...	24 %
Bending test (cold bending) ...	1½ in. bent through 180° without fracture

Such results, I think it will be agreed, are satisfactory from every point of view. Of course it would be unnecessary to use steel of that quality except in very high-speed machines. For ordinary sizes where the speeds are lower, steel of considerably less tensile strength would be used and the factor of safety would still be more than ample. The tests are not limited to the longitudinal direction. British steel-makers are prepared to supply forgings with the physical qualities mentioned, and to subject them in both the radial and tangential directions to tensile as well as cold bending tests. Up to the present time we have not been able to get American steel-makers to guarantee these radial test-pieces. Quite recently, tests were carried out upon a rotor forging for a large machine running at 3,000 r.p.m., and the results obtained were as follows:—

	Longitudinal	Radial	Tangential
Ultimate tensile strength (lb. per sq. in.) ... ..	90,000	83,200	88,000
Elastic limit (lb. per sq. in.) ... ..	54,000	45,200	40,000
Elongation (in 2 in.) ... ..	29 %	28 %	28½ %

All the bending tests were satisfactory at 180°. Radial test-pieces would be taken probably not more than 3 to 4 inches from the surface. I think it will be agreed that the results may be considered highly satisfactory, and that with such material there should be no difficulty in constructing large generators to run at 1,500 or 3,000 r.p.m. In order to make a comparison with the machines mentioned by the author we must consider a 1,500-r.p.m. machine, which would be the standard speed for this country. It would have a diameter of say 55 in., and the weight would probably be in the neighbourhood of 30 tons. It may be of interest to give some further details as to the procedure which one of the leading British steel-makers would adopt in the manufacture of such large rotors. They would start with an ingot of approximately 115 tons, diameter 94 in., and 50 per cent of the ingot would be cut off at the top end to ensure homogeneity of the material. It would be forged down to the required diameter in a press of about 12,000 tons, the ends, of course, being forged down in a smaller press. The reduction in area would then be about 2½ to 1, so that the work done would be quite considerable. After the rough machining of the rotor it would be thoroughly annealed; and in the process of annealing probably more would be done to the quality of the steel than is generally appreciated. In connection with the internal stresses in the rotor, which, as the author points out, are high, unless the material is treated exceedingly carefully in the finished rotor there would be, as shown in Fig. 11, a number of radial ducts dividing the rotor into sections to a considerable depth, say 6 to 8 inches.

Those ducts would naturally tend to release the stresses in the longitudinal direction. The slots for the coils and the ventilation ducts under the slots would to a certain extent release the stresses in the tangential direction; in the finished rotor, therefore, the remaining initial stresses should be fairly well released. Being assured of a supply of steel of suitable quality which would enable us to construct these large machines with solid rotors, this design has certain advantages which cannot be neglected. In the matter of the critical speed, for example, it would seem to be exceedingly difficult to calculate the speed of a structure such as that described; it may be possible, but the accuracy would probably not be so great as that with which it is possible to calculate the critical speed of a solid rotor. Where it is necessary to calculate the critical speed accurately, the solid rotor would therefore seem to have distinct advantages. I am not quite clear whether this is so or not in regard to the rotor described by the author, but it seems as if the calculation of the critical speed would depend largely upon the solidity of the plates, that is to say on these being absolutely flat—if they are not flat the rotor would be elastic. I should be much obliged if the author would indicate whether that is correct or not. In another way the solid rotor would have an advantage. Owing to the stiffness of the construction it would be possible to use a smaller diameter for a given output, which, of course, would give slightly better efficiency. With the solid rotor it would also be possible to use self-contained blowers in many cases where, with the construction described by the author, it would not be possible owing to the increased length required for the blowers. In some cases that would be an advantage. The outside slip-rings are a feature of considerable importance in cases where high critical speeds are required. The rings take up a good deal of room in the construction, with the result that the critical speed must either be reduced or the diameter of the rotor shaft must be increased. By placing the slip-rings outside the bearings the distance between the bearings can be considerably reduced, and at the same time another objectionable feature mentioned in the paper, namely, high peripheral speed, will be obviated. Greater accessibility in attending to the slip-rings will also be obtained. It is quite feasible to make a satisfactory design for the outside slip-ring. One objection against the solid rotor at the present time is its cost. Taking the material alone, the cost would be in the ratio of 1 to 1·6 in favour of the disc construction. To some extent this would be counterbalanced by increased labour on the discs, but the ultimate cost of a rotor constructed with plates would probably be slightly less than that of a solid rotor.

Mr. A. E. McKENZIE: Dealing with the ventilation of the rotor, the author states on page 69 that it becomes incumbent upon us to use a ventilated rotor and to put up with the disadvantage that this necessitates cleansing the air supply before admission to the generator. Will he in his reply explain what is this disadvantage, since most engineers are in favour of cleansing the air before it is sent into the generator. I should like to express my appreciation of the 3-part wedge (Fig. 5). Only those who have to do with the fitting of solid wedges can appreciate the very great difficulty of making a satisfactory job of a wedge perhaps 6 or 7 ft. long; it becomes almost impossible with the present high peripheral speeds

where the stress is something like 1 ton per square inch at the surface of the key. I have known considerable trouble to arise through keys working loose, even when they have been inserted with pressures of 20 to 25 tons per square inch. Considering external short-circuits, the author indicates that there is still considerable difference of opinion as to advisability of dispensing altogether with external reactances in generator circuits. There are advantages undoubtedly in having external reactances, particularly when a fault happens to develop on the windings close to the machine terminals. In such a case the high internal reactance will be found of little use in reducing the shock to the system, whereas external reactance would considerably reduce the current flowing to the faulty machine from the others working in parallel with it. The Manchester Electricity Department has recently specified that all large machines shall be built to withstand a short-circuit at their main terminals when running at normal speed and fully excited; but under the present condition of things we have hesitated to apply that test. The author mentions that the large machines were designed to have a short-circuit current of 14 times the normal. Some tenders I have recently inspected for 15,000-kw. machines have given such a high internal reactance of the machines that the momentary short-circuit current would be only seven times the normal. No reference has so far been made to hollow conductors. I have seen several machines which have had windings of tubular and rectangular form so that the air is carried right through the conductors. I imagine that the cooling air must be more effective in these designs than where it comes into contact with a very small portion of the conductor periphery. With the circular type the insulating tube can be much more easily and safely wound without fear of cracking than with the rectangular type where there are four difficult corners to negotiate. I shall be glad to hear whether the author has had any experience with machines wound in that particular manner. Mr. Seaton has mentioned that recent troubles with turbo-alternators have occurred on the stators only. In the past there has been considerable trouble with built-up rotors, but all the solid rotors I have had experience of have given absolutely no trouble whatever. I should be very sorry indeed to have to revert to the older types. Temperatures of 120° C. to 180° C. are only possible with machines having mica-wound insulation. Machines that I have had to run did not attain anything like that temperature, but being wound with ordinary cotton insulation gave considerable trouble.

Dr. G. W. WORRALL: I should like to mention one or two points in connection with ventilation. The author has pointed out one disadvantage of the use of fans on the rotors, namely, the extra length required. In my opinion it is desirable in nearly all cases to have external fans, because a much better system of ventilation is obtained and nothing is lost from the point of view of overall efficiency. Axial ventilation is better than radial, and the trend of design seems to be in that direction. I have seen several elaborate systems of air ventilation; but complicated air paths should be avoided, and, above all, the ducts should be so arranged that they can be cleaned. I have had considerable trouble with breakdowns of the end windings of rotors; as the author points out, it is almost impossible in building machines to apply to

windings the actual pressures which occur when the machines are running. I should like to ask him whether the windings move, and if so, whether they take up a permanent set after the first few times of running, or whether they move outwards and inwards each time the machine is started and stopped.

Mr. R. TOWNEND: I have had considerable experience with the design and construction of the type of rotor described by Professor Walker, and it has certainly proved highly satisfactory. A number of such rotors have been built, and in all cases the temperature of the windings has been extremely low. One might imagine that trouble would be experienced with the large number of joints between the slot bars and the end connectors, but this has not proved to be the case. All the rotors built with this type of winding have had soldered joints, and these have proved perfectly satisfactory. However, in order to remove this objection entirely, it should not be an unsurmountable difficulty to weld the bars electrically to the end connectors. In connection with the design of turbo-alternators, I should be pleased if the author could give any information with respect to the large losses due to eddy currents in different parts of the machine. If a turbo-alternator be run on short-circuit and the driving power be measured, this power (after deducting the friction and windage loss) is considerably greater than the calculated stator I<sup>2</sup>R loss. This difference may be 2 per cent, or even more, of the normal output of the machine. If this eddy-current loss could be reduced to one-half, it would mean an increase in efficiency of 1 per cent, and also a considerable reduction in the heating of the machine. There appears to be very little available data as to where this loss actually occurs, its magnitude in different parts of the machine, and the extent to which it is influenced by different load conditions. The last edition of the Standardization Rules of the American Institute of Electrical Engineers advises that for the purpose of obtaining the efficiency of an alternator the whole of the measured short-circuit losses should be included, but I think this gives a value which is slightly lower than the true efficiency. A thorough investigation of this subject of stray losses in turbo-alternators is extremely desirable, and should give valuable results.

Dr. W. CRAMP: It is always difficult to criticize a "permissive" paper, i.e. a paper wherein the amount of information given is limited by some commercial consideration, so that progress and profit are mutually opposed. Though this is the case in the present instance, it must not diminish our gratitude to the American Westinghouse Company who have certainly allowed the author to say more than most of their English competitors would. Nevertheless, it is difficult to judge the author's arguments without more technical data than he actually quotes. I have therefore been obliged to deduce as much as possible from suggestions which he gives, and in this way I have calculated the field winding and other details such as the flux per pole, which would appear to be about 100 million lines. From these data it is possible to estimate the corresponding densities, as well as the weight of the rotating copper, and thus to obtain an idea of the limitations imposed by the very high speed. It should be pointed out in the first instance that the example selected is not one of the most difficult, since no large commutator

Cramp. is involved. Apart from this, however, the author has shown that the first general limitation is the frequency; and that the second is the strength of the material available. He lays great and appropriate stress upon the concurrent development of material and design which has rendered the combination of large output with high speed possible. In considering this matter I should like to remark how cordially I approve of the use throughout the paper of the term "yield point" instead of "elastic limit"; but I cannot find any suggestion in the paper as to what the author considers to be a safe stress with respect to a given "yield point"; i.e. no indication is given of the factor of safety employed. It seems to me worth while to point out another limit, not mentioned in the paper, beyond which any increase of peripheral speed may lead to an uneconomical design. This limit is introduced by a consideration of the fact that in a slotted rotor when certain limiting densities are decided upon there is a corresponding maximum slot area. Thus, if we assume that no flux passes straight down the slot and that the ratio of the flux density in the air-gap outside a given pair of slots to the flux density at the roots of the teeth is known, then the depth of the slot is given by the expression

$$R(1 - K - mK)/(1 + m),$$

where  $R$  = rotor radius,

$m$  = ratio of the width of slot to the width of tooth at the rotor periphery,

and  $K$  is the flux density ratio just assumed.

Similarly the width of the slot =  $\phi m/(1 + m)$ , where  $\phi$  is the slot-pitch at the periphery of the rotor.

Thus the area of the slot ( $A$ ) is given by

$$A = \phi R \left[ \frac{m - mK - m^2 K}{(1 + m)^2} \right]$$

whence

$$\frac{dA}{dm} = \phi R \left[ \frac{1 - K - mK - m}{(1 + m)^2} \right]$$

Here  $\frac{d^2A}{dm^2}$  is obviously negative, so that  $1 - K - mK - m = 0$  is a condition for  $A$  to be a maximum; whence

$$m = (1 - K)/(1 + K)$$

for maximum slot area. Here  $\phi$  has been regarded as decided by factors independent of  $K$ , which is usually the case. It is also worth while remarking that under any circumstances the depth of the slot must be such that  $r > K(1 + m)$ , that is  $> 2K/(1 + K)$ , so that there is a limit to the possible value of  $K$ . In many cases the maximum possible slot area demands a slot the proportions of which are for other reasons undesirable; but the calculation at least shows in which direction maximum output lies. Now the area of the slot multiplied by the space-factor, by the specific weight of copper, and by the square of the velocity, and divided by  $gR$ , is a measure of the centrifugal force acting upon unit axial length of the tooth root. Equating this to the section of the tooth root multiplied by the safe stress corresponding to the material used will show whether the most economical design as dictated by electromagnetic considerations is consistent with the peripheral speed and material proposed.

Taking the figures which the author has *not* given Dr. Cramp. and employing them in this way, I come to the conclusion that designers are approaching the limit when they will not have material which will carry the stress corresponding to the maximum copper they can get into the slot. When we arrive at that point the question arises: What shall be done? Two things can be done: either the slot dimensions may be changed (which may entail waste of material), or the material in the slot may be changed—for instance, aluminium may be used. There does not seem to be any reason why a designer should not use aluminium, and it would be interesting to know whether and to what extent it has been tried. On page 68 the author points out the necessity of knowing not only the physical characteristics of the material but also its history. This is a new factor of great importance. With regard to critical speed I entirely agree with what the author has said, but I find that designers in this neighbourhood do not take the same view. When I specified a turbo-alternator in which the critical speed was to be above the speed at which the machine ran, a well-known designer came to me and said that there was no necessity for any such limit, and he was sure that no one would be willing to pay for it.

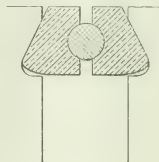


Fig. E.

I take it that that attitude will now be abandoned. On page 69 the author says, with regard to the critical speed, that the action of the rotor is not the same as it would be if the shaft were separated from the rotor itself. I have not been able to follow that statement clearly. He says: "This is mentioned as a matter of more theoretical interest than of great practical importance." It seems to me to be of great practical importance. As regards ventilation, he says that "The system which lends itself best to the other features of the machine that we shall have to adopt is one combining an axial passage underneath the winding slots with a radial discharge distributed over a fairly wide central portion of the rotor." That is questioned by many designers; it is thought that pure axial ventilation is very much better when it can be accomplished. It seems to me that this statement is rather didactic and must be based upon some test figures which I hope the author will give. The disadvantage of the 3-part wedge shown on page 70 is that the edges of the teeth will be rather liable to be damaged by forcing in the wedge. It seems to me that it will be difficult to get the wedges to "bed" properly all the way along; one will be tighter or looser than another. A type of wedge which I think could easily be used is shown in Fig. E. On page 70 the author refers to oscillograph tests of the effect of this 3-part wedge construction. It would be interesting to see the oscillograms. If there had

Mr. Cramp.

been time I should have liked to go more fully into the question of the air-gap reluctance as affected by the stator slots, but I can only say that Mr. Carter's paper on "Air-gap Induction" is a very fine example of what might be carried out to a very much greater extent. But it would be reasonable in the case of such large machines as this to go to the trouble of working out the special case in considerable detail. If it is argued that such a calculation wastes too much time and is too difficult, I would still point out that we have Hele-Shaw's apparatus which can be used; and if that again is difficult to calculate from, it is quite possible to get a fair geometrical approximation graphically by the use of proportional dividers. That also is, however, too long a subject to go into to-night. On page 75 a formula in connection with the pole-face loss is given. The author says: "While it is not possible to compare, say, an engine-driven machine with a turbo-generator on the basis of this criterion, the figure has been found to furnish some kind of guide between one machine and another of similar type." I wonder if I shall be indiscreet if I ask for those figures. Again, on page 76 he says: "It can easily be shown to what extent this transposition will avoid eddy-current losses." That is a subject with which we are accustomed to couple the name of the author, and I hope that he will give us the reference to a paper in which it can be found.

Mr. Dutton.

Mr. H. DUTTON (*communicated*): The following are a few particulars relating to some 6-pole 2,200-r.p.m. continuous-current turbo-generators of which I have had operating experience over a period of 5 years:—Length of iron in armature  $10\frac{1}{2}$  in.; diameter 27 in.; peripheral speed about 15,600 ft. per minute. The shaft is solid, being turned and planed to a 6-wing star section where it passes through the armature and commutator. The iron consists of thin laminated plates threaded and keyed on one of the wings of the star, with bronze end-drums on which the overhanging ends of the armature bars are carried. In the later designs these armature bars are tied down by bronze rings, pressed on over the insulation, these rings being secured by screws to the body of the rotor stampings and also to the aforementioned drums. Serrated rings of bronze are interposed to form ventilating spaces between the laminations. In the earlier designs this tying-down of the overlapping ends of the armature bars was done by steel binding wire, sweated and bound on; this, as the author points out, was a source of magnetic leakage, and, as we discovered, anything but an ideal arrangement. The centrifugal stresses set up in the armature windings when the machine was run, gradually forced these through the insulation and so on to the binding wire. The latter, being theoretically a spiral line, did not present a plane surface to withstand the stresses. A short-circuit thereupon occurred, and the binding wire being burned through, the ends were thrown out, and catching in the stator winding were torn off completely, leaving the armature bars at this point unbound. These naturally followed, and many of the lugs were torn off, both at the armature bars and at their attachment to the commutator; some of them went through the roof and the neighbouring machines were covered with pieces of binding wire, causing a flash-over on one machine. Fortunately no one was injured, and the turbine governor fulfilled its function of controlling the speed of the machine. In my opinion a serious error in

Mr. Dutton.

this case was the fact that this binding wire was put on in one piece, so that when the short-circuit occurred the whole of the wire was affected. In the repair the makers agreed to my suggestion to put the wire on in four sections, so that in the event of a recurrence of such a short-circuit one part only would be affected and the remaining ones would probably be sufficient to prevent the bars being thrown out. Thicker insulation has also been used, so that the binding wire may present a surface equivalent to half the diameter to meet the stresses. The ventilation of these machines is performed simply by the suction due to the rotation of the armature and the air spaces along the star-shaped shaft and through the stampings. A fan was tried but was found to be unnecessary, as the temperature was not appreciably diminished by its use. No air screens are used, and no bad effects from dust have been experienced after 5 years' operation. In this machine air is drawn into the armature beneath the commutator bars, and also from the back end of the armature. This arrangement might, be improved, as the back end being nearest, and the air friction accordingly less, most of the air required is drawn in through this end, the air passage through the commutator being confined and tortuous. A better plan would be to set up a diaphragm in the armature body, so proportioned that the air drawn in by the motion would of necessity have to pass partly through the commutator and so assist in keeping this cool. Similarly shaped wedges are used for closing the slots and confining the armature bars, as are described in the paper; but these are made of hard wood only, and are pressed in sections, with the grain in the direction of rotation. That these are sufficient for the purpose was proved by the accident previously mentioned, when these wood wedges held the remaining portion of the armature bars in position, and withstood the strain of the lugs being torn off. We have had no trouble with these wedges, although the otherwise unbound length of the armature bar is 20 in. They are, however, securely bound at each end, and the author has evidently overlooked the effect of the tensile strain in the bars themselves which would appear if they tended to rise in the centre of their length, also the friction of the sides of the slot. The first critical speed of these machines occurs at 1,470 r.p.m., so that the running speed (2,200 r.p.m.) is beyond this, and they operate in this respect quite satisfactorily. One trouble with machines is to get a quite satisfactory balance at the operating speed. A rotor must be in nearly perfect balance to work with success at such high speeds. The method of doing this, after trying end adjusting with the usual knife-edge supports, is to rotate the body of the rotor at the required speed and mark with a pencil; afterwards to run up to the same speed in the opposite direction and again mark. These marks will be found not to coincide, and the true position for the added balance is diametrically opposite to the mean between these two marks. The reason of the marks not coinciding is that the slight eccentricity acquires a momentum of its own, and the mark is therefore always somewhat in advance of its true position. Some of these added weights are of the nature of half an ounce, so that the accurate balancing of a high-speed rotor is a most delicate operation. Regarding the preservation of balance, a further difficulty occurs with a continuous-current machine when grinding the commutator. Ours is of

r. Dutton. 13 in. diameter and the peripheral speed therefore 7,500 ft. per minute. The working speed of the carborundum wheel used in this operation is 1,700 ft. per minute, and the grinding must necessarily be done at this speed or thereabouts. It does not follow that because a commutator is ground true at 1,700 ft. per minute that it will be so at 7,500 ft. per minute, and it may be necessary to re-adjust the balance after the operation. The idea of providing copper conductors in the chrome-nickel steel ring which is described is both novel and good, but in my opinion it is better to avoid the necessity for this by the selection of some non-magnetic material, as is done in our machines. The paper certainly deals with a machine of greater size, speed, and capacity than those we have, but the whole question seems to be a matter of proportioning the material used, and of course the ultimate strength of the material selected. Generators are usually protected by circuit breakers, especially where they have to run in parallel, but the provision of reactance coils is becoming increasingly popular in large, projected and completed plants. Where step-up transformers are used, the practice now adopted is to place these between the generator and the busbars, on the grounds that it is easier to control pressures than currents; and in such circumstances the provision of reactance coils hardly appears to be necessary. I cannot see what useful purpose is served by short-circuiting a generator at its terminals as is suggested on page 74, and beyond proving the carrying capacity of the armature windings, or finding the weakest point, it could only result in unnecessary straining of the machine. I have seen an alternator short-circuited at its terminals and started up thus; this was done after the armature has been partially rewound, with the object of drying out the insulating varnish and baking the coils. The engine would not drive the alternator at much more than half speed when so arranged, and no readings were taken of the current and pressure. Running up on a short-circuit is of course a very different matter from short-circuiting a machine when at full voltage. I should like to add that many of the initial troubles have been overcome, and that with the steam end of the sets we have had absolutely no trouble.

Professor A. B. FIELD (*in reply*): Replying to the remarks of Professor Walker, it is possible that a 50-in. solid forging for 1,500 r.p.m. may prove a desirable construction in this country. I have used solid forgings in the States for rotors somewhat over 40 inches; and from various statements during the discussions it appears that steel-makers in this country may have something to offer which is not readily obtainable in the States. In severe cases where forgings are used, we must look for the properties not only in a longitudinal and tangential direction, as referred to by Professor Walker, but also in a radial direction and at a depth at least corresponding to the root of the tooth; in buying the material from the steel mills the manufacturers will probably be obliged to insist upon such specifications as the basis for acceptance or rejection. Professor Walker has shown two most interesting slides exhibiting the construction of his rotor winding, and Mr. Townend, who has also had considerable experience with this type of winding, has given evidence of its excellence. In his winding Professor Walker gains a great advantage by using a large number

of comparatively small slots, which greatly helps the transference of heat from copper to iron, and allows of shallower slots and less total copper section being used. From a manufacturing point of view, narrow slots and thin teeth are not as advantageous as large ones, when we are dealing with these big structures which have to be slotted from the solid. I believe that a great deal has yet to be done in the matter of improving rotor windings; and while the construction described in the paper is sure to be improved upon, I think that Professor Walker's construction also may probably be more of a guide to a final design than the result in itself. Professor Walker refers to sinking the stator conductors into the core even when a magnetic wedge is not required, and thus obtaining ventilation on the air-gap side of the coil. In some large 25-cycle machines constructed three or four years ago in the States we adopted such an arrangement, using two slot wedges, the intervening space serving for ventilation purposes. In some cases this mechanical separation is of very great value also, as pointed out, by reason of the reduction of losses in the stator conductors due to stray rotor flux.

Mr. Kuyser's ingenious system of axial ventilation is interesting, having been devised to obviate the difficulty introduced by comparatively large central radial vents. It has the disadvantages incident to blind-end vents, and the air resistance is doubtless increased compared with other arrangements. But apart from these considerations, the only objections to it appear chiefly to be manufacturing ones. Mr. Kuyser has had the benefit of considerable experience in the States with the machines described in the paper, so that his contribution along these lines is the more welcome. For the same reason, his comparison of the stator winding described in the paper with the types more commonly used in this country is instructive. The difficulties of adequately bracing the latter types of winding, which difficulties appeared at one time to be serious, seem now to have been practically overcome. Reference has been made in the discussion elsewhere to the question of rotor-coil bracing, and I still believe it to be quite desirable, apart from the numerical estimates of the possible forces, to adopt rotor bracing in the case of the 2-pole large rotors in the present state of our knowledge. I should also hesitate much to depend upon the result of a shrink fit for the driving of the chrome-nickel steel end-rings, instead of the use of keys.

We are encouraged to hope, from the remarks of Mr. Juhlin, that the difficulty of obtaining satisfactory material in large steel forgings may not be so acute in this country as in the States. Should the properties mentioned by him for the 80,000-lb. steel be also obtainable on radial test-bars taken at a depth corresponding to the bottom of the teeth, and the material at the centre of the forging be satisfactory, while the whole forging is sufficiently free from initial stresses, we should find in such a forging excellent material for these rotors. The tests quoted for the material of a 3,000-r.p.m. forging are also instructive, although it would have been desirable to have had the radial bar taken further from the surface. On the other hand, we must remember that the diameter of a rotor for 3,000 r.p.m. does not involve the difficulties of material referred to in the paper; in fact, all rotors for this speed and above, for which the author has been responsible, have

Professor:  
Field.

Professor  
Field.

been made from solid forgings. Answering Mr. Juhlin's question with regard to the critical speed of plate-built rotors, it is undoubtedly necessary to have the plates sufficiently parallel to ensure proper compression surfaces around the bolts, in order to obtain the requisite critical speed. Reference has been made to this in a discussion elsewhere, and it has been pointed out that the slotting of the rotor facilitates this condition. I entirely agree with Mr. Juhlin's remarks as to the advantages of external slip-rings from many points of view. It is simply a question of balancing up these great advantages against the objection to carrying the conductors for excitation through a hollow shaft, with its consequent difficulties.

From the remarks of Mr. McKenzie it is clear that I have ill expressed my meaning with regard to the use of filtered air, as there can be no question, from the point of view of the manufacturer or the designer, of the great advantages obtained by this filtration. Further, it is nearly certain that almost all important stations in the future will ultimately use filtration or washing of the air used for cooling purposes. A few years ago, however, in the States there was a considerable opposition on the part of operating engineers to the complications, space, and inconvenience involved by air filtration. Referring to the momentary short-circuit current of these large machines, I would ask Mr. McKenzie whether the figures he gives for 15,000-kw. generators, viz. seven times normal current, really refer to short-circuiting under the worst possible conditions, namely, at the instant of zero voltage across the terminals to be short-circuited. The maximum current in this case is twice that corresponding to what might be considered as effective internal reactance. I can give no information as to the use of hollow conductors referred to; the only cases of this nature that I remember refer to low-voltage transformers in an installation at Niagara Falls, in which hollow rectangular conductors were used with water circulating in them.

In reply to Dr. Worrall, there is bound to be a slight motion of the rotor windings each time the machine is started and stopped, corresponding to the slight elastic increase of diameter of the end-rings. This effect is extremely small. There is probably also a very slight motion of the copper in the slot, due to the fact that the initial pressure is less than that arising upon rotation. This effect has not proved sufficient to cause trouble in the type of rotor described, after many years' operation. The point has to be carefully watched, however, in the design of the winding, as insulation trouble is apt to occur if the copper be closely confined at, or too near to, the corners of the coil.

Mr. Townsend has drawn attention to the importance of short-circuit losses, and I fully agree with him that it is a most important subject for further investigation. It appears certain that these large losses are not very local, or we should have further trouble from them. They must be distributed over the rotor surface, stator end-plates, and stator core, as well as slightly in the stator copper. From some tests upon large alternators of the water-wheel type, in which two machines connected together have been operated at zero power factor, it has been possible to determine fairly well the power supplied to the pair of machines, representing the total losses, under such load conditions; and I have generally found that such total

losses checked fairly well with the separately-measured losses, allowing nearly the whole of the short-circuit losses. It is probable, however, that some reduction should be made, and of a variable amount for different types of machines, on account of the completely different flux densities when operating on load and on short-circuit.

Dr. Cramp has given an interesting account of the relations determining permissible slot sizes, etc., in the rotor. So far, however, the tooth stress has not been the main limiting consideration in these machines; otherwise it would be worth while to use nickel steel for the plates, which would not greatly increase the cost. The difficulty of supporting the copper external to the rotor body is more apt to limit us here. As to the method of rotor ventilation, one difficulty of a purely axial system is that of obtaining sufficient cross-sectional area for the air supply. By admitting air at each end of the rotor, the available section is instantly doubled. Further, by a partially radial system we easily obtain a sufficient cooling surface of the steel. In a system of axial ventilation developed by Messrs. Siemens in Germany, a considerable steel surface is obtained by using a tooth with parallel sides, thus providing a vent space between the tooth and the cell accommodating the winding. Such a construction involves considerable workshop difficulties, and I should judge that the practical advantage obtained is much greater from the point of view of having a uniform tooth section allowing of the use of less ductile material, than from a purely ventilating point of view. With a simple axial system there would also be difficulty in separating the air exhausting from the rotor, from the ingoing air to the stator, unless a purely axial ventilation of the stator were also adopted. In casually asking for practical data upon pole-face losses Dr. Cramp perhaps hardly appreciates at what cost in actual money and mental worry such information has been obtained. In large engine-type alternators with solid poles I have had reason to be cautious when the product of the factors mentioned in the paper approaches 95, and in the case of turbo-generators when the figure approaches 130. The danger increases, however, much more rapidly with an increase of this product than would be the case if the figure were really proportional to the watts-per-sq.-in. pole-face loss. The above figures represent the product

$$X^2 Y^2 V^2 \lambda^{-1}$$

where X has the same value as  $B/(\lambda B_0)$  in the reply to

Mr. Carter's remarks in the Birmingham discussion:

Y = ratio of the kilo-ampere-turns for the single air-gap, to the actual length of single gap in inches;

V = peripheral speed in thousands of feet per minute;

$\lambda$  = slot pitch in inches.

Dr. Cramp also refers to the eddy-current losses in the stator conductors, and seeks information as to the effect of transposition of strands. Most cases can be approximated to sufficiently well for practical purposes by using the results given in my paper on the subject published

by the American Institute of Electrical Engineers in 1905, or by methods similar to those indicated there. The most important cases not dealt with there are those of chorded windings. In such cases, and when we have in each slot two coils (as many coils as slots), there occurs an overlapping of phases, so that the current in the lower conductor is out of phase with that of the upper one in the same slot. This may apply to all, or only to some of the slots, according to the coil pitch.

In those slots in which the phase of the current is the same in the top and bottom conductors, the results in the paper give sufficient information generally. In those slots in which we have a phase difference of  $60^\circ$ , the bottom conductor has the normal loss irrespective of coil pitch, while the top conductor, if solid, has a loss corresponding to  $m = 1.82$ , instead of 2\*. Similarly, if we have a phase difference of  $90^\circ$  between the currents in the top and bottom conductors, and again have solid conductors,  $m$  should be taken as 1.62 for the top and 1 for the bottom conductor; while for a phase difference of  $180^\circ$  between the two conductors  $m$  should be taken as unity in both conductors. This generally means that in the case of a chorded 3-phase winding with solid conductors arranged two deep, the extra loss in the outer conductors of slots in which the phases overlap is 72 to 78 per cent of that in the slots in which the phase is the same in both layers; while for the 2-phase machine the corresponding figure is 53 to 57 per cent. In the case of laminated conductors, two

deep in the slot, representative figures are as follows:— For a 3-phase machine, with winding chorded two-thirds and with the conductor twisted over at one end of the coil, the extra loss may be taken at roughly 80 per cent of what it would be for an unchorded winding having the same mean turn and active length as the actual winding. Again for a 2-phase machine with a coil pitch of half the pole pitch, this figure is about 60 per cent. These figures naturally vary, however, with the proportions of the machine. The effect of lamination and transposition for full-pitch windings can be sufficiently closely estimated by the methods given in the paper referred to above.

Mr. Dutton advocates the use of non-magnetic material for the retaining rings at the ends of the rotor. The value of this advice would be enormously enhanced if accompanied by some indication that there is a suitable material commercially available at present. Non-magnetic 25 per cent nickel steel can be obtained having an ultimate strength of approximately 80 per cent of that of the chrome-nickel steel referred to; but such material has its yield-point at only about 50 per cent of its ultimate, compared with the 80-85 per cent for chrome-nickel steel; while even at low stresses it has properties more like those of a bronze than a steel. It is possible to produce non-magnetic manganese steel with nearly the strength of chrome-nickel steel, but so far the material has been practically unworkable except by grinding. A practicable high-tensile non-magnetic steel would be a very great boon in many engineering directions.

\* See the paper referred to for notation.

## INSTITUTION NOTES.

## LOCAL HONORARY SECRETARIES AND TREASURERS.

The following have been appointed by the Council to be Local Honorary Secretaries and Treasurers of the Institution :—

- Mr. H. Hastings, for Spain.  
Mr. A. C. Kelly, for Argentina.  
Mr. W. M. L'Estrange, for Queensland.

## ASSOCIATE MEMBERSHIP EXAMINATION.

The following Regulation has been approved by the Council :—

During the period of the war and for such further period thereafter as in the opinion of the Council it may be advisable, any candidate for admission as Associate Member who is engaged on naval or military service or employed (whole time) in an engineering capacity on munitions or other war work will be exempted from complying with the Examination Regulations; and any such service may at the discretion of the Council be accepted in part fulfilment of the conditions laid down by the Institution as regards experience, provided that in other respects the candidate satisfies the requirements as regards age and training.

## EMPLOYMENT OF DISABLED SAILORS AND SOLDIERS.

The Council have requested the National Service Committee of the Institution to formulate a scheme for giving to disabled sailors and soldiers a preliminary training as switchboard attendants, etc.; and for obtaining means to carry on this work and arranging for the selection and distribution of applicants for positions.

## DIVISIONAL ENGINEERS, ROYAL NAVAL DIVISION.

The Institution has been asked by the Officer Commanding the Divisional Engineers of the Royal Naval Division to arrange for a number of lectures (technical or non-technical) to the men (about 400) now at Blandford Camp, Dorset. Any member willing to offer his services for this purpose, or in a position to suggest some one able to do so, is requested to communicate with the Secretary of the Institution.

The first of the lectures under the auspices of the Institution will be given by Mr. Frank Gill.

There are no fees attached to the lectures, which should if possible be illustrated with lantern slides.

## APPEALS FOR BOOKS.

The Council has received appeals from the Board of Education for books and magazines for :—

- (a) The Camps Library, i.e. for camps, and for soldier prisoners in Germany;  
(b) Civilian prisoners interned at Ruhleben.

In the case of (a), books of the following descriptions are welcome :—Historical and Scientific Works, Poetry, Essays, works on Economics, Biographies, Pocket Dictionaries and Grammars (particularly French and German), volumes of well-known series such as the Home University Library, pocket Shakespeares, text books on Mathematics and Science.

Bulky books are unsuitable. All should so far as possible be of small size and light, and each complete in one volume. All books intended for (a) should be handed, unwrapped and unaddressed, over the counter at any Post Office.

In the case of (b), Dictionaries and Grammars, and works on Science and Languages, History, Education, Law, etc., are required for use in connection with the numerous classes which have been formed at Ruhleben under the auspices of the Camp Education Department, the subjects of study being as under :—

- (1) Languages (English, French, German, Italian, Russian, Spanish, and Dutch);
- (2) Arts (History, Philosophy, Music, and Drawing);
- (3) Commercial (Shorthand, Book-keeping, Business Methods and Correspondence, Banking, Commercial Law, and Political Economy);
- (4) Engineering (ordinary—7 subjects);
- (5) " (special—6 subjects);
- (6) Mathematics and Science;
- (7) Elementary Physics;
- (8) Navigation;
- (9) Drawing Office Work and Handicrafts.

In this case lists only of the books offered (author and title) should be sent to A. T. Davies, Esq., Board of Education, Whitehall, London, S.W., from whom information will be received in due course as to which of the books are accepted for despatch to Germany.

## ACCESSIONS TO THE REFERENCE LIBRARY.

KINGSLAND, W. Notes for signallers: Morse, semaphore, and station work. Written specially for the use of Volunteer Training Corps.

sm. 8vo. 18 pp. London, 1915

MAYCOCK, W. P. Alternating-current work. An enlargement of, and an improvement upon the author's former work "The alternating-current circuit and motor."

sm. 8vo. 439 pp. London, 1915

MORSE, S. F. B. S. F. B. Morse, his letters and journals. Edited and supplemented by E. L. Morse.

2 vol. 8vo. Boston, 1914

MURDOCH, W. H. F., and OSCHWALD, V. A. Electrical instruments in theory and practice.

sm. 8vo. 374 pp. London, 1915

MURRAY, D. Press-the-button telegraphy. [Reprinted from the "Telegraph and Telephone Journal," Nov., 1914, to July, 1915]. 8vo. 53 pp. [London], 1915

- NATIONAL ELECTRIC LIGHT ASSOCIATION. Electrical meterman's handbook. Written and compiled by the Committee on Meters. Revised and presented at the 38th Annual Convention June 7-11, 1915.  
sm. 8vo. 1,341 pp. [New York], 1915
- OWEN, D. Recent physical research.  
8vo. 156 pp. London, [1913]
- PATENT OFFICE LIBRARY. Key to the classifications of the patent specifications of France, Germany, Austria, Netherlands, Norway, Denmark, Sweden, and Switzerland, in the Library of the Patent Office.  
3rd ed. sm. 8vo. 190 pp. London, 1915
- PATERSON, G. W. L. Electric mine signalling installations.  
sm. 8vo. 204 pp. London, 1914
- PEEK, F. W. Dielectric phenomena in high voltage engineering.  
8vo. 280 pp. New York, 1915
- REY, J. De la portée des projecteurs de lumière électrique.  
8vo. 162 pp. Paris, 1915
- RICHEY, A. S. Electric railway handbook. A reference book of practical data, formulas and tables. By A. S. R., assisted by W. C. Greenough.  
sm. 8vo. 843 pp. New York, 1915
- RIDSDALE, C. H., and RIDSDALE, N. D. Analyst & client. A few notes on chemical and physical testing and other technical matters, with seventeen original tables and a special section on electrical conductor rail tests, for railway and works' managers, engineers, etc.  
8vo. 198 pp. Middlesbrough, 1915
- RIVINGTON'S notes on building construction. A book of reference for architects and builders and a text-book for students. new ed. entirely rewritten [by various authors]. Ed. by W. N. Twelvetrees.  
2 pts. 8vo. London, 1915
- ROYAL SOCIETY OF LONDON. Catalogue of scientific papers. 4th series: 1884-1900. vol. 14, C-Fittig.  
4to. 1,024 pp. Cambridge, 1915
- RUTTER, J. O. N. Gas lighting: its progress and its prospects; with remarks on the rating of gas-mains, and a note on the electric light.  
8vo. 71 pp. London, 1849
- RYAN, W. T. Continuous and alternating current machinery problems. Elementary problems for use in technical schools. 8vo. 45 pp. New York, 1915
- SEMENZA, G., and SEMENZA, M. Graphical determination of sags and stresses for overhead line construction. Translated by C. O. Mailloux.  
4to. 34 pp., 13 charts. New York, 1915
- SMITH, A. B., and CAMPBELL, W. L. Automatic telephony. A comprehensive treatise on automatic and semi-automatic systems. 8vo. 419 pp. New York, 1914
- SMITHSONIAN PHYSICAL TABLES. 6th ed. Prepared by F. E. Fowle. [Smithsonian miscellaneous collections, vol. 63, no. 6].  
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8vo. 511 pp. Oxford, 1915
- UNITED STATES: DEPARTMENT OF COMMERCE. Circular of the Bureau of Standards. no. 20, 31, 37, 47, 48, 49, 54.  
8vo. Washington, 1914-15
- 20, Electrical measuring instruments. [2nd ed.]
- 31, Copper wire tables. [2nd ed.]
- 37, Electric wire and cable terminology. [2nd ed.]
- 47, Units of weight and measure—Definitions and tables of equivalents.
- 48, Standard methods of gas testing.
- 49, Safety rules to be observed in the operation and maintenance of electrical equipment and lines.
- 54, Proposed national electrical safety code. [Preliminary ed.]
- VAN DEVENTER, H. R. Telephonology. 3rd ed.  
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## THE INSTITUTION.

### ADDRESS TO THE STUDENTS' SECTION,

By J. E. KINGSBURY, Honorary Treasurer.

(Address delivered 6 December, 1915.)

When your Secretary asked me if I would give an Address at your Opening Meeting, he was good enough to suggest a subject. It was one of which I am supposed to know something, and of which I do know something in a general way; but there are others who know it in detail very much better, and so far as its technicalities are concerned there are probably amongst you some who know a great deal more than I do. Whilst I was unwilling to decline the honour of addressing you, I thought I would take a subject which involved less preparation, upon which I might make a slip but should not need a slide, a subject the notes in connection with which I might make on the back of an envelope. When I was asked for a subject I found some difficulty in selecting it. Finally I thought that perhaps to you and to me the subject of the Institution was one upon which our joint interests would justify my taking up some of your time; and now I begin to repent and to wish that I had had more time for research and more opportunity for thought and classification in the presentation of the subject which I selected.

Of course there are a number of Institutions, but to you and to me there is but one, and that is why I use the definite article, "the" Institution. The Institution of Electrical Engineers is in one respect not unlike a man who has been raised to the peerage and has changed his name twice, once when some dignity has been added to it, and on a second occasion when he has reached his ultimate fame and changed his name altogether. The Institution of Electrical Engineers in its initial stage was the Society of Telegraph Engineers, and at a later stage it became the Society of Telegraph Engineers and of Electricians. The original Society was formed in 1871, and its objects as indicated in the first Rules and Regulations were the following:—

"Objects: The Society of Telegraph Engineers is established for the general advancement of electrical and tele-

graphic science and more particularly for facilitating the exchange of information and ideas among its Members."

Of course that was by no means the first Society that had been established to exchange ideas amongst its members, and one point of interest to us is to consider when mankind began to think that they could by putting their heads together promote the advance of science and thereby the good of the world. In the direct line we have to go back to about 1645, when a number of people, whom we should call amateurs, formed a small Club which consisted "of divers worthy persons inquisitive in natural philosophy," and particularly in what was then called the new philosophy or experimental philosophy. That Club met weekly in London for the discussion of philosophical questions, and later developed into the Royal Society, which was formed in 1660 and received its Charter of Incorporation in 1662. Of that Society John Evelyn was one of the founders and Samuel Pepys one of the later members. It is of interest to note that two men so different in character should have two things in common—membership of the Royal Society and the habit of keeping a diary, to which habit we are indebted for a more intimate acquaintance with that age than perhaps we are with any other. The Royal Society continued its discussions, investigated problems, and did an immense amount of work for the advancement of knowledge. One of its most important achievements was the development of that taste for the gathering together of kindred spirits to thrash out problems of mutual interest. That tendency grew in the succeeding century to such an extent that in 1754 the Society for the Encouragement of Arts, Manufactures, and Commerce was founded. Numerous other Societies followed, and the interest extended from what may be called general questions to those which were more definite. The interest of society in engineering developed greatly. In the intervening period Brindley had constructed the

Bridgwater Canal, and Smeaton had built the Eddystone Lighthouse, and there was a Smeaton Society formed in the eighteenth century. The interest in engineering grew so that the Institution of Civil Engineers was founded in 1818 and received its Charter 10 years later. I think we may regard the Institution of Civil Engineers as the earliest and most important of the various Engineering Societies which were formed. There were numerous other Societies founded, but the tendency of them all was to become specialized. The Society founded for dealing with pure science realized that it was impossible to follow the details of all the sciences, and consequently various departmental Societies were formed for the specific object of dealing with particular branches.

What happened in the case of pure science has happened with engineering. I was a little surprised, on investigating this subject for the purpose of this Address to-night, to find that no details had been prepared of the formation and development of this Institution, except a very brief account which was prepared at the time when Mr. R. K. Gray was President in 1903, when a Telegraph Conference took place and a concert was given at the Albert Hall in honour of the delegates to that Conference. I hold in my hand a programme, which contains a brief résumé prepared by General Webber of the main activities of the Institution up to that time. There is evidence of hurried printing and it was probably hastily compiled. The only other published information that I have seen is in "Scientific London," a book published in 1874, when the Society had been formed two or three years, and the author of that work, when dealing with the Society of Telegraph Engineers, makes a very definite indication of its formation through and from the Civil Engineers. He says: "At the commencement of the present decade [1870-1880] it was felt by many eminent electricians and Members of the Institution of Civil Engineers that the department to which they had devoted themselves had at length assumed such imposing proportions as to demand a separate and special organization. Far from opposing the development of that new body, the parent Society in Great George-street at once extended a helping hand to the scheme and offered free use of its handsome room for the meetings of the new Society. To Major Frank Bolton and to Major Webber, R.E., is due the inception of the idea of a Society of Telegraph Engineers, and these gentlemen were warmly supported by Messrs. Robert Sabine, Latimer Clark, and Dr. C. W. Siemens."

General Webber says in the notice referred to above, that it was in the autumn of 1870 at the instigation of Sir Francis Bolton and himself that seven or eight gentlemen whose occupations connected them with the application of Electrical Science and Telegraphy met together with the object of starting the Society, and in May 1871 they were joined by 60 others, when the first officers were nominated and elected on the 30th June.

I have been a little surprised to find the importance of the telegraph profession or industry, if we may call it so, at that period. In the course of some statistics prepared by Sir James Anderson, who was one of the pioneers of ocean telegraphy, which were presented to the Statistical Society in 1872, it is stated that the total amount of the capital invested in submarine telegraph companies, exclusive of the Government Indo-European

line, amounted to £10,230,370, and the total length of the cables was 37,795 miles. That does not take into account at all the investment in inland telegraphs, which amounted to something like £7,500,000. So that you see the interests of telegraphy at that period were very considerable, and it was undoubtedly time that a Society was established to deal with its work. Hitherto papers on telegraphic subjects had been read at somewhat infrequent intervals before the Institution of Civil Engineers, but obviously they were not sufficient to sustain the interest of telegraph men. A special Society was needed. As I have said, a special Society was formed in 1871 and held its first meeting on the 28th of February, 1872, when Dr. C. W. (later Sir William) Siemens delivered the presidential address. I hope your interest in the Institution may prompt you at some time to read that first presidential address. You will find in it much food for thought, but I will quote what he says regarding the formation of the Society:—

"Our future prosperity will be influenced in a great measure by the direction in which we shall start upon our pilgrimage. Let us hope, therefore, that our joint efforts may lead us in the direction of true scientific and practical advancement.

"But before we set out upon our labours it behoves us fairly to consider whether there is need or scope for a Society of Telegraph Engineers? Is Telegraph Engineering not a branch of Civil Engineering, and do not all our proceedings therefore fall within the legitimate sphere of action of the Institution of Civil Engineers? Or if we meet with difficult questions in physical or mathematical science, is not the Royal Society or Section A of the British Association open for us to discuss them, or may we not go before the Institution of Mechanical Engineers with any purely mechanical question? Is it desirable, indeed, it may be urged, to take a branch from the parent stem and to cultivate it separately; shall we not degenerate thereby into 'specialists,' or what may be called 'fractional quantities of scientific men,' and this in face of the patent fact that the further we advance in scientific knowledge (whether pure or applied) the more clearly we perceive the intimate connection between its different branches, and the impossibility of cultivating one without constantly reverting to the others.

"In answer to such allegations we may fairly assert that we do not intend to become 'specialists' in the narrow sense of wishing to confine the range of our knowledge to the phenomena and appliances which have an immediate application to our professional objects. We are, on the contrary, sensible to the fact that in order to master those special branches of knowledge thoroughly we shall have to travel into adjacent fields and build our practice upon the widest possible scientific foundation. But our time is limited, and, although the great principles of nature may be understood generally by one person, their applications are infinite, and all we may hope to do is to attain to a general scientific basis, and with it to devote our energies vigorously to the details of one or two branches of applied science."

I have alluded to the changes in name which have arisen since the formation of the Institution, but reference

to the proceedings shows that although the original title had a limited scope no such limit existed in its objects. It was always intended that the whole field of electrical science and activities should be covered. This is clear from another quotation I will give you from Sir William Siemens' address:—

"Problems of pure electrical science meet the telegraph engineer at every turn. . . . There is hardly a problem in electrical science that is not of practical interest to the telegraph engineer; and considering that electricity is not represented at present by a separate learned society, ranking with the Chemical or Astronomical Societies, I am of opinion that we should not exclude from our subjects questions of purely electrical science."

This broad outlook was emphasized by a subsequent speaker at the opening meeting (Mr. C. F. Varley, F.R.S.), who said:—

"This Society, I assume, will gradually, by natural selection, develop more into an electrical society than into a society of telegraphy proper; and the moment it is understood that all papers on electricity, or bearing directly upon the development of electrical science are admitted, it at once takes the science out of the narrow groove into which it seemed to be drifting, into the most extensive of all grooves, because it will be found ultimately to embrace every operation in nature."

It was not until 1880, however, that steps were taken to broaden the title of the Society. In December of that year a resolution was passed amending the title by the addition of the words "and of Electricians." An example of the interest which the members have always taken in the details of the Society's work is to be found in the discussion which arose at the meeting as to the necessity of the word "of." On behalf of the Council it was explained that the point had already been canvassed in all its bearings and the word was retained. In the Council's Report of 15 December, 1881, it was stated that

"the proportion of scientific names to be found among the list of members elected this year seems to afford evidence that this alteration of the title has certainly assisted in making better known a fact which appears to have been previously only partially recognized, viz. that the Society is established to promote electrical science in all its branches."

This first change of title followed the invention of the telephone and the early applications of arc lighting, but a further change was shown to be desirable from the developments of the eighties. The "subdivision" of the electric light and the utilization of incandescence for illumination; the proposals for the use of electric motors; and the transmission from Paris to Glasgow of a "marvellous 'box of electricity,'" which Lord Kelvin called an "accumulator," were all events of the early eighties, and by the end of that decade the scope of electrical engineering was widely recognized. It was in 1880 that the present title was adopted. I do not know of any record of the fact, but it seems reasonable to infer that the form was adopted from that of the Civils. It was

recommended to the members with due regard to the susceptibilities of telegraph engineers who might regret the disappearance of those words from the Society's name, but such members cordially supported the change and the Institution loyally maintained its interest in the older applications.

The membership of the Society in its first year was 110. "The members included Ronalds, Wheatstone, Cooke, Bain, and a host of others who must for ever be associated with the history of telegraphy in this country, many of whom are still amongst us, and I think it is a fortunate thing and an honour to have so many of them as Members of our Society." These words were spoken by Mr. Latimer Clark, and his own name is equally honoured by us as the others.

The Secretary has been kind enough at my request to compare the existing List of Members with the original List, and I find that happily there are 24 of the original members still amongst us. I will not take up your time by reading their names, although these are very interesting, but we still have Professor Carey Foster, Sir John Gavey, and Mr. Alexander Siemens, all of whom are Past-Presidents, and such familiar names in telegraphy as Messrs. A. W. Heaviside, J. Rymer-Jones, H. R. Kempe, P. V. Luke, and Dr. A. Muirhead. You will also be interested to hear that the name of one student is to be found in the first published List of Members, namely, Edward Palliser. In the second List of Members, corrected to the 1st January, 1873, the name of another student was added, Graham, W., Henley's Works, North Woolwich. In the third List, corrected to the 9th April, 1873, there were three more names—Gatehouse, Thomas; Hooper, Samuel; and Hayes, Alfred. As you know, the number of students has grown since then, and, if I judge rightly, your Chairman will take care that they grow still more in future. The membership of the Institution has risen from 110 in its first year to 6,811 of all classes as at the 1st May, 1915, as stated in the last Report. As you know, the membership now consists of Members, Associate Members, Associates, Graduates, and Students. The Associate Membership class and the Graduates did not exist at the original formation of the Institution but were introduced at later periods. Another point of interest to you will be that the Students' Meetings were established early in the life of the Society, i.e. in 1887. The activities of this Institution are probably greater than those of any other engineering or scientific body, due in part to the very happy thought, which was carried into effect in 1899, of establishing Local Sections. The Local Sections of the Institution enable a very much larger proportion of the members to exchange ideas than in any other Institution. It has an added value from the fact that the Institution is thereby enabled to throw into the common stock of knowledge the specialized information which is acquired in Local Centres due to local industries or applications.

The Institution, being a collection of individuals, has some of the attributes of individuals, and one of the most pressing ideas in most men's minds at some time or other is to have a home of their own. That feeling came to the members of the Society quite early. Hitherto they had enjoyed the hospitality of the Institution of Civil Engineers, but they felt that a home of their own, be it ever so humble, was desirable, and accordingly in 1894

a Building Fund was established as a beginning. Those of you who have made any study of the Accounts of the Institution, even if you have not an intimate knowledge of its earlier history, will know that the Institution has a property in Tophill-street, Westminster. That property was bought as the groundwork of the home of the Institution. The fund which had been raised up to that time was invested in purchasing the freehold of the property in Tophill-street, and efforts were made to get a new fund to erect a building, Westminster, as you know, is the engineering centre of London. There is a reason for everything, even for trades or professions settling in particular places. I presume the reason that the engineering profession is largely domiciled at Westminster is due to its proximity to the Houses of Parliament, through which most large engineering ventures have to go at some time or other, so that the nearness of the engineer and the Parliamentary agent to the Committee Rooms of the House is a matter of considerable importance. By reason of its engineering locality the Institution decided at that time upon the purchase of the Westminster property. When the Institution had saved up enough money to justify the commencement of a building, the area available was obviously insufficient for an Institution which was growing at a greatly increasing rate—at a rate which the development of electrical applications must necessarily still further increase. Consequently, when the question of building a home for the Institution came up again, its locality was further considered. The Westminster feature is of less importance in electrical engineering than in some other branches, and to us, scattered as we are in so many ways, a central situation is really better, because both the Westminster man and the City man can reach the central situation readily, and electrically the City is just as important to us as Westminster, perhaps more so at times. Consequently, when the building in which this meeting is being held came into the market, the Institution very carefully considered the matter and felt that the opportunity was one not to be neglected, and accordingly this building was acquired. The hospitality which we had hitherto received from our progenitors, the Civils, for which we shall always be grateful, we try to pass on so far as we can to other Societies which have electricity at least in common with us, but which have been formed for the discussion of subjects of interest pertaining to some special branch.

I think you may be interested if I call your attention to one or two of the features of interest of this particular ground. The probability is that a considerable part—I am not sure just how much—of the ground upon which this building stands is engineering ground. The Embankment in front of the building is the work of engineers, and it is not so ancient but that I can remember its formation. The ground upon which this building stands was considered in 1881, when this circular I hold in my hand was issued, as “possessing many associations of historic interest, being close to the Savoy Chapel, and in the ‘precinct of the Savoy,’ where stood formerly the Savoy Palace, once inhabited by John of Gaunt and the Dukes of Lancaster, and made memorable in the Wars of the Roses.” The circular from which I am reading is the original circular dated 6th October, 1881, that D’Oyle Carte issued in regard to the building of the Savoy Theatre, which was

the first theatre in London to be electrically lighted. That event took place on the 10th October, 1881, it having been deferred for some few days “in consequence of it having been found impossible to complete the working of the electric light in time for it to be shown to-night”—I am reading from a printed note which was distributed amongst the audience in the theatre at the time. A portable 60-h.p. engine, which drove four dynamo machines each requiring 18 h.p., stood on the plot of ground immediately in front of this building—I am reading from my own notes which I made at the time. I noted that only the auditorium of the theatre was lighted electrically, and I estimated from the lights I counted that there were about 200 lights altogether. I also have a note which says: “The lamps are stated to cost 25s. each.” That brings us somewhat close in our association with the Savoy, but it does not exhaust the points of interest in the locality.

To begin with, take the engineering features of Waterloo Bridge. Canova, the Italian sculptor, who saw it about the time that it was finished, just a century ago, described it as the finest bridge in Europe and alone worth a journey from Rome to see. I doubt whether any engineer can have a better example for the design and construction of a work for a definite object and a work more pleasing to look at for its simple lines than that excellent example of private enterprise. Waterloo Bridge is well worth the thought of any engineer. If anybody wants to see what effects can be obtained in the changeable London atmosphere, and to note at the same time the constructional beauties of an engineering work, he cannot do better than see the sun set over Waterloo Bridge as viewed from some point midway between Blackfriars and Waterloo. That is somewhat of a digression, but I want to tell you also that Somerset House was at one time the home of the Royal Society, and at King’s College, occupying its east wing, Wheatstone did all his work, or most of it, in connection with the telegraph. The shot tower on the other side of the river is the shot tower with whose proprietors Wheatstone made an arrangement for the landing of an insulated wire which was to be taken across the river from King’s College in order to demonstrate the feasibility of sending an electric current under water. As a matter of fact, the experiment was never carried out. Cooke, Wheatstone’s partner, explains why, but it was contemplated that it should be done.

This building having been acquired by the Institution, was transformed so that it was almost impossible for people who knew anything of it before to recognize it in its new guise, so far, at least, as the theatre and the entrance hall are concerned. A great deal of care and thought were given by the Council of the period to the construction of the theatre, and as a result I think we may consider that we have a finer theatre and a more suitable place for holding our meetings than any of the other learned Societies of London.

That brings me to tell you of the Library. I have already said that among the first members of the Institution was Ronalds, the man who invented the first telegraph, although it never came into use. Ronalds was one of those men of science and literature who have been desirous that other people should have the opportunity of knowing all that has been recorded in the science in

which they are interested. Although he was unable to persuade the powers-that-be that a telegraph was necessary, he still maintained his interest in electricity and he compiled a Catalogue, a copy of which I hold in my hand. A brief biography of Ronalds was included in a "little handbook" entitled "Memoirs of distinguished men of science of Great Britain living in the years 1807-8" published by "E. & F. N. Spon 16 Bucklersbury." The *Telegraphic Journal* of 2 July, 1864, reprinted the Ronalds biography, of which the last paragraph is as follows:—

"Mr. Ronalds is now (April 1864) residing at Battle, in Sussex, and during the latter years of his life has spent much time, and part of his small pension, in collecting and collating an electric library, which might be conveniently available for the advancement of his favourite science, and prove worthy of presentation or bequest to some British public institution, so as to form the nucleus of one which might approximate possibly to a complete electrical library."

Our own was the fortunate "British public institution" to which the library was confided under circumstances which our first Librarian records in a report annexed to the Report of the Council for the year 1878. Mr. A. J. Frost says:—

"Sir Francis Ronalds, who became one of the earliest members of the Society, died in 1873, bequeathing the library to his brother-in-law, Samuel Carter, Esq.; and this gentleman, in accordance with the wishes of the testator that the library should be made available for students of electricity, handed the same over to the Society on certain conditions, one being that the Society should bear the cost of printing the Catalogue, which it had been the labour of the author's life to complete. The Society, although a very young one, willingly undertook the charge, and has spared no expense in making it worthy of its author, and of its importance in relation to science and bibliography.

"The Catalogue contains upwards of 12,000 entries, and is believed to contain a record of nearly all the important books and papers bearing on the subject, published in any language, up to within a short time of its author's death."

You will understand that this Catalogue is not merely a list of books on the shelves, whose titles have been transcribed. It is a list of all the published works relating to electricity which Ronalds could discover. Mr. Frost says that in compiling it Ronalds made use of the card system, using a separate slip for each entry. As this Catalogue was commenced probably as early as 1820, Mr. Frost thought that Sir Francis Ronalds might be numbered amongst the earliest to see the advantages of that system. We all make a considerable use of the card system now—perhaps without recognizing that its origins were so remote.

The Council reported (11 December, 1878) that 91 pages of the Ronalds Catalogue were then in type, and that arrangements were being made for further portions being set up forthwith. It would obviously be desirable, even if only on the score of economy, that the whole should be set up and printed at once, but unfortunately the number of subscriptions received up to that time would not, it was

to be feared, permit of that being done. The Council expressed their disappointment and emphasized the great value which the Catalogue would possess as a work of reference. In this Catalogue you will find against the names of the books a dagger or an asterisk, or no mark at all. The dagger or the asterisk indicates that the Ronalds Library contains the work so marked. Where there is no mark against the book, the work is not there. It happened not very long ago that I saw a copy of *Chambers's Journal* for sale, and turning it over quite casually came across an article which I thought was interesting. I found it was one of the early articles on the electric telegraph, dated 1840. I turned up the Ronalds Catalogue and found that that entry had neither a dagger nor an asterisk against it. I have brought the book along with me this evening, and I think the best thing I can do is to ask the Chairman to take care of it and hand it over to the Institution.

The books in the Ronalds Library when transferred to the Institution numbered about 6,000. The Library Committee has made systematic efforts to obtain missing works, but many deficiencies still remain, and if any student comes across an early electrical work which he thinks ought to be in the Library I hope he will at once refer to the Ronalds Catalogue and see whether it is here or not. The Library as a whole is, however, the most complete electrical library in existence, and if any Student wishes to pursue any particular subject I cannot conceive any better way of doing so than by utilizing "the treasures buried in books," as Ruskin expressed it, contained in this Library. A list of 22 of the rare books in the Library dating from 1551 to 1823 is given in the *Journal* of the Institution for 1880, the Ninth Volume, page 333; and that list of what I have called our treasures has been increased quite lately by the donation of the Faraday books and papers, which were presented here only a few weeks ago. It is most satisfactory to think that the Institution now has in its Library some of the work of Faraday's own hands. This Library was brought together by Ronalds in the interests of science, and it should be utilized to the full by every exponent of science. I do not suggest that any of you should come here and attempt to read all the books, but in the immediate future, when recreation may need to be of an economical character, you may find some advantage in devoting attention to some detail which is of interest in your electrical work. Including the Ronalds Library the books in the Library of the Institution now number about 12,000 volumes. Those of you who may desire to investigate the treasures of the Library will find in Mr. Cortesey a librarian whose ready and cordial assistance you may rely upon receiving: I speak from experience.

The Library has, as its necessary accompaniment, a Museum, which is not by any means as complete as we should all like it to be. But it is growing, and it is important that interest in the Museum should be sustained, although it is obvious that, under present circumstances, it is not reasonable for the Institution to spend either time or money on such things as museums, when other important considerations are pressing upon us. At the same time I am sure you will agree that any object of interest which ought to be retained for the information of future ages should not be lost. We want to save objects of interest, because when you bear in mind the interest attaching to the "Rocket," for example, you can imagine

the interest some of our descendants will take in our early electrical apparatus. Museums have always been a feature of scientific societies. The old Royal Society in its early days had a museum, which they called a "Collection of Curiosities."

You know as well as I do the value of the Proceedings as published in the *Journal* of the Institution, which include particulars of all the important discoveries, inventions and applications in the electrical field, but I am not at all sure that, speaking generally, the value of *Science Abstracts* is so readily recognized. I should like to emphasize the importance of the engineer knowing the progress that is being made in the various sciences, and *Science Abstracts* gives you—in a concentrated form, it is true, but in a form which tells you enough to put you on the right track for getting detailed information if you want it—a résumé of everything that is being done in other branches of science—the discoveries, if I may put it so, that are being prepared to be tackled by you. You do not want any feature of that kind to escape you, and if you watch *Science Abstracts* carefully you ought not to lose anything. *Science Abstracts* is the joint production of the Institution and the Physical Society, and I commend it to the attention of all students.

Now I wish to go for a few moments from the publications and the building to individuals. The Presidents and Officers of the Institution have been drawn from all branches of electrical engineering enterprise. Nothing could show more clearly the catholicity of outlook of the Institution than the names of its Presidents. Read the list on the tablet at the entrance to the theatre, or on the first and second pages of the List of Members, and you will see how thorough the Institution has been in obtaining the experience of men in all branches of the electrical profession. But the Presidents do not cover the whole ground. The permanent officials, particularly the Secretary, of an Institution like this are extremely important individuals. The first Secretary of the Institution, who was also one of its founders, was Major Frank Bolton, and he was succeeded by Mr. Wilson, Mr. George Preece, Sir James Sievwright, who was Secretary for a short period, Mr. Langdon, Mr. F. H. Webb, whom most of us knew, and then Mr. McMillan. Mr. McMillan was untiring in his energies; able as an administrator, and as considerate a man as it would be possible to find. His devotion to the interests of the Institution it is hardly possible to express. On the unhappy decease of Mr. McMillan, Mr. Lloyd was appointed Secretary in his place, and when Mr. Lloyd returned to the Society with which he was originally engaged, the Iron and Steel Institute, he was succeeded by Mr. Rowell, who happily was brought up in the McMillan school, and who I think is carrying on the greatly increased work of this Institution in the same kind of way in which it was performed by Mr. McMillan. Then we have also on the staff as our chief clerk Mr. Tree, who I believe attends to the Meetings of the Students, and who has a longer knowledge of the Institution than any of us. I am not quite sure, but I think that for about 50 years he has been in the service of the Institution. Prior to that he was in the office of Major Bolton, who was one of its founders, so that you see the Institution has been fortunate in the men who have worked for it.

I have referred a good deal to the past in connection

with the Library, the Royal Society, and so on, but I do not want you to infer that I am attributing too much importance to the past. At the time the Royal Society was holding its early meetings at Gresham House in Bishopsgate-street, John Milton was writing "Paradise Lost" in Bunhill Fields; and at the time those gentlemen with scientific leanings were seeking knowledge on abstruse points the poet put into the mouth of Adam the phrase:

"... To know  
That which before us lies in daily life  
Is the prime wisdom";

and, a few lines later, remarks that much seeking for knowledge of a less practical kind renders us

"... In things that most concern  
Unpractised, unprepared, and still to seek."

You in your work, as we in ours, will not be able to devote an exceptional amount of attention to the acquiring of ancient knowledge. It will be as much as you can do perhaps to carry out your daily work; in regard to which avoid by all means the possibility of being "unprepared and still to seek." The tendency of the time differs materially from what it used to be. The past in the records of this Institution is largely made up of individual work or individual inventions. The future is more and more becoming the work of a number. The individual invention does not happen with the frequency that it did, and it may not happen to any of us. The Joint Stock principle, which originated and has been largely adopted in England for investments, has not, I think, developed as fully as it might in the direction of engineering work, and if I may suggest one thing to you it would be that in your daily work, whilst not neglecting any opportunity of individual invention, you should try and avoid the cultivation of what I might call the inventor's vanity. There have been many examples of inventor's vanity in electrical work, perhaps a prominent one being that of Wheatstone himself. He was a very able man, but I am afraid he was very much afflicted with inventor's vanity. The opportunity of a great invention does not come every day. The necessity of bread and butter does. It may be that you in your daily work may have to obtain your bread and butter without the opportunity of doing anything which will make your name famous in a wide area, but nevertheless it may be very productive work, and provided it be not overlooked within the narrow spheres in which you are working, it may be that you will have to be content with that recognition. It may be possible that the inventive faculty should be suppressed. There is a very well-known instance of that on the part of Cooke, the partner of Wheatstone. Wheatstone had somewhat reflected on Cooke's lack of invention in later years, and Cooke explained that when the instrument department was placed under his supervision "It became my duty to examine and advise upon a great variety of inventions constantly submitted to my inspection. The incentive to re-enter the field of invention was great, and the faculty can hardly be denied to me; but, in the position which the Board wished me to hold, any rivalry with the inventors who brought their schemes for my examination would have clashed with the duties which I undertook to perform. I resolved, therefore, to aid and encourage others, but never more to

compete with them. During the last 10 years very many inventors have fearlessly confided their secrets to me; and I am happy to say that it has been in my power to assist several meritorious men, by recommending their discoveries to the patronage of the Electric Telegraph Company."

Some of you may possibly be in a position of similar responsibility, in which the inventive faculty, if it assumes the form of a patent, for instance, may be detrimental to your doing that work which you have undertaken to do. But again let me say that the inventive faculty must not be suppressed by any means. We need it all, but if possible avoid the assumption that the possession of a patent is a proof of ability.

I remember that at one time an application came before me for some post or other, and amongst the qualifications mentioned by the applicant was that he had taken out numerous patents. It so happened in that particular case that that kind of qualification was not a recommendation. Anybody can get a patent by paying a fee at the Patent Office, and the tendency to overvalue work of your own and the impossibility of arriving at an opinion as to the merits of an invention until it goes before an independent and impartial judge, render it inadvisable to attach too much importance to every production of that kind.

But do not misunderstand me. I do not suggest that you should in any way repress the inventive faculty. The inventive faculty is essential in the production of new and improved processes for the saving of labour, and for many other things, but it is seldom that a man can now do such work by himself. He does it as part of the work of somebody else, perhaps under the direction of somebody else, and in that way contributes to the sum of improvement just as much and perhaps a little more than if he tried to do it by himself.

I feel that I am trying your patience, and therefore I

will conclude with a few more words only. This Institution, some of whose history I have been trying to give you, is in your hands in the future. Some of you will be Members of Council. Those of you who are not will be able to criticize those who are. Those who are will, I am sure, heartily welcome criticism which has for its object the welfare of the Institution. Very valuable suggestions on behalf of the Institution have—at all times—been made by the members, but the value of the work will, I think, be greater if you say to yourselves when the time of criticism comes: "Do I propose this primarily for the benefit of the Institution, or do I propose it because I have some object to achieve in which the advantage to the Institution is a secondary consideration?" When the time comes for you to criticize those of your fellows who may be Members of the Council, bear in mind that responsibility carries with it care. It is not permissible for a trustee to engage in speculative investments, and it follows that careful consideration of any new proposal is necessary on the part of those who occupy positions of responsibility. I am quite sure that, by your help, the Institution may rely upon a future which will be even more brilliant than its past, and that the varied developments and applications which have arisen during its past life will be eclipsed by the infinitely greater and more important ones which will arise in the future.

That brings me back to the point which was alluded to by your Chairman in his opening remarks, that to him is entrusted the responsibility of this Students' Section at a time when so many of your members are away on other work. Those of you who are still at home are, I know, engaged in strenuous work on behalf of the nation, but, having decided to continue your Students' Meetings, I think it does behoove you to support your Chairman in his object of attaining as large attendances as possible and good discussions at the meetings of the Students' Section.

# NOTES ON THE IGNITION OF EXPLOSIVE GAS MIXTURES BY ELECTRIC SPARKS.

By J. D. MORGAN, Associate Member.

(Paper first received 5 August, and in final form 12 October, 1915; read before the BIRMINGHAM LOCAL SECTION 15 December, 1915.)

## GENERAL THEORY.

The ignition of an explosive gas mixture by a spark is commonly considered to depend upon the communication of heat from the spark to the gas. When approaching the subject it is natural to suppose that the ability of the spark to ignite the gas can be expressed in terms of the heat energy of the spark. On examining the subject experimentally, however, a suspicion is soon created that ignition

"cannot ignite a coal-gas jet in spite of the obviously high temperature of the sparks."\* Assuming that heat alone when accompanied by sufficient temperature is capable of causing ignition, it would apparently be right to suppose that the mode of producing electric sparks containing sufficient heat could have no effect upon the igniting property of such sparks. This, however, is not found to be the case.

Fig. 1 shows two sets of curves obtained by Professor

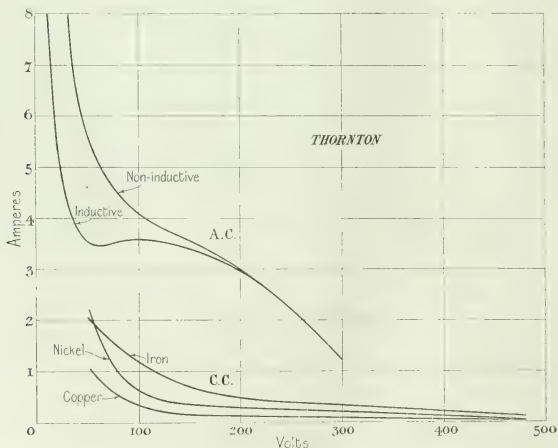


FIG. 1.

depends partly, if not entirely, upon some cause other than heat. It is a commonplace of ordinary experience that to produce ignition the temperature of the igniting means must not be below a certain definite value. This fact appears to have led to the belief that temperature is the determining factor in ignition. It is well known, however, that if the temperature is not accompanied by a sufficient quantity of heat ignition will not occur. Certain diminutive electric sparks will not ignite a highly inflammable gas, yet their temperature may be well above the ignition temperature. Glowing cordite emitting a spray of sparks

Thornton† for the least single sparks in continuous-current and alternating-current circuits which will ignite a coal-gas and air mixture. Without going into details it is at once apparent from the curves that a greater amount of energy is required to produce an igniting spark by an alternating current than by a continuous current; and the

\* H. F. COWARD, C. COOPER, and C. H. WARRINGTON, "The Ignition of Electrolytic Gas by the Electric Discharge," *Transactions of the Chemical Society*, vol. 101, p. 2278, 1912.

† W. M. THORNTON, "The Ignition of Coal-gas and Methane by Momentary Electric Arcs," *Transactions of the Institution of Mining Engineers*, vol. 44, p. 145, 1912.

relationship between the number of volts and amperes in the circuits immediately prior to the production of the sparks differs in character in the two cases. This fact is in itself sufficient to prompt the question: Does ignition depend upon some factor other than heat? A variety of experiments suggest a reply. If an iron wire heated by an electric current (continuous) be held over the disc of a charged electroscope, it will be found that when the wire first becomes visibly hot there is no effect upon the electroscope and gas cannot be ignited. On gradually increasing the current a condition of temperature is attained at which the electroscope steadily discharges. It is at this temperature that ignition occurs. In a paper by Professor Thornton\* a similar experiment with platinum wire is mentioned, and in the same paper there is recorded the most interesting and important result found by Mr. J. R. Thompson, that "it is possible to ignite a cold explosive mixture by the incidence of X-rays on a platinum surface in it."

Another experiment bearing on the subject consists in so adjusting the spark gap between a pair of pointed poles in the high-tension circuit of an induction coil that in neither air nor coal gas alone can a spark pass, but the poles emit a faint blue glow or brush discharge visible in darkness. If the poles are contained in a small chamber into which an explosive coal-gas and air mixture is introduced, it is found that after an interval, which varies with the size of the gap, the gas explodes. The time can be made to vary from a fraction of a second to as much as two minutes. If the gap is too large no explosion can be produced. When the explosion flame appears, a spark at once passes, due to the greater electric conductivity of the ionized gases, and often persists for a second or more after the flame has vanished. This experiment is somewhat at variance with one performed by Professor Thornton. In another paper† he states in connection with a brush discharge from leaky steam pipes that "gaseous mixtures cannot be fired by such a discharge or by the more active discharge from needle points at extra high pressure, unless a definite spark passes." As a matter of fact the spark appears to be the consequence and not the cause of combustion.

Experiments such as those above described all suggest the ionic origin of ignition. It has been shown that where a hot wire or spark is the source, ignition only occurs when ionization is produced, and ionization alone without heat has been found to be capable of causing ignition.

In the summary of an investigation by Dr. H. F. Coward‡ of the limiting pressure for ignition with a high-tension sparking arrangement, the opinion is expressed that "the ignition of an inflammable gas mixture is largely governed by the two factors, namely, (a) its thermal conductivity, and (b) the energy degraded when the discharge is passed." He also states, however, "that the experiments (described in his paper) do not prove whether the ignition is ultimately a thermal or an electronic effect." This quotation is given as showing that investigators of

ignition phenomena are inevitably driven to suspect, if not to accept, the ionic origin of ignition. Whatever be the final decision, there is sufficient evidence, as above indicated, for now stating that ionization alone is capable of causing ignition, and ionization accompanies the common electrical methods of ignition.

In a general way it is well known that gas mixtures are only combustible when the proportions lie within certain limits. These limits, for methane and air, have been carefully worked out by Dr. Wheeler, and the least single igniting spark for mixtures between these limits have been investigated by both Wheeler and Thornton. Mixtures of methane and air containing less than 5·6 per cent, and more than 14·8 per cent, of methane are incapable of ignition.\*

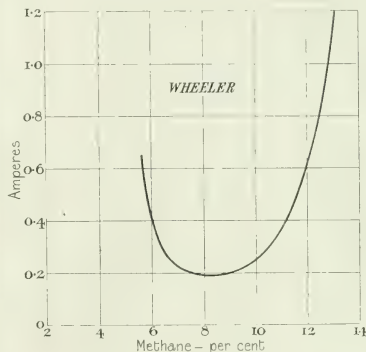


FIG. 2.

Fig. 2† shows how the least continuous current required to produce a single igniting spark varies with variations in the gas mixture. Single sparks were produced between platinum points by a contact breaker arranged in a bell circuit in which the voltage and inductance were kept constant. It will be seen that the most sensitive mixtures lie between 7·5 per cent and 9 per cent of methane. The chief value of this curve is to show the limits of inflammability and the general character of the current variation between those limits. With different values of voltage or inductance different current values would be obtained, but they would all lie within the same limits of mixture.

Using continuous current Professor Thornton finds the curve to assume, as shown in Fig. 3,‡ a different form from that shown in Fig. 2. The ordinates of the curves in Figs. 2 and 3 are not comparable, since the least igniting current diminishes as the voltage or inductance increases.

\* M. J. BURGESS and R. V. WHEELER. "The Limits of Inflammability of Mixtures of Methane and Air," *Transactions of the Chemical Society*, vol. 105, p. 2591, 1914.

† R. V. WHEELER. Home Office Report on Battery-Bell Signalling Systems, 1913.

‡ W. M. THORNTON. "The Electric Ignition of Gaseous Mixtures," *Proceedings of the Royal Society, A*, vol. 90, p. 274, 1914.

\* W. M. THORNTON. "The Electric Ignition of Gaseous Mixtures," *Proceedings of the Royal Society, A*, vol. 90, p. 274, 1914.

† W. M. THORNTON. "The Limiting Conditions for the Safe Use of Electricity in Coal Mining," *Report of the British Association*, p. 513, 1914.

‡ H. F. COWARD, C. COOPER, and J. JACOBS. "The Ignition of Gaseous Mixtures by Electric Discharge," *Transactions of the Chemical Society*, vol. 105, p. 1059, 1914.

It will be noticed that a portion of the curve in Fig. 3 follows closely a straight line which passes very nearly through the origin. From this Professor Thornton argues that the igniting current is proportional to the number of molecules of combustible gas in unit volume of the mixture.

Using alternating current the character of the curve alters and assumes a symmetrical form, as shown in Fig. 4, the current varying as the "square of the excess of either of the combining gases on each side of the point of maximum inflammability."

A common method of defining the least spark which will ignite a given gas mixture is by specifying the number of volts and amperes, or the number of amperes and the inductance in the circuit prior to the formation of the spark. On the assumption that this gives a measure of the ability of a spark to ignite a gas (or the "incendivity" of the spark), the validity of the method has been rightly

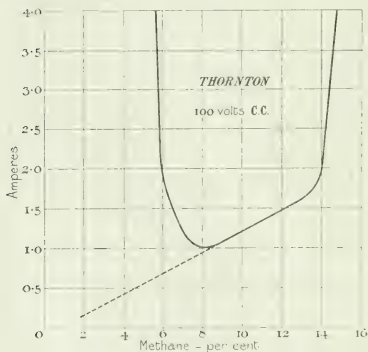


FIG. 3.

questioned. For both inductive and non-inductive circuits there seems to be no sufficient reason, as will be explained later, for the assumption that the energy associated with a circuit prior to sparking can be regarded as a measure of the incendivity of the spark. Nevertheless there is a practical value in curves showing the relationship between the number of volts and amperes, or amperes and inductance, in circuits which when broken give rise to sparks capable of igniting a given gas mixture, for they indicate conveniently the practical conditions under which dangerous sparking becomes possible.

Fig. 1, already referred to, shows curves for continuous current in a non-inductive circuit provided respectively with copper, nickel, and iron sparking poles, single sparks being produced by single rapid breaks between the poles. These curves give the various values of the volts and amperes which produce the least sparks capable of igniting an 11 per cent mixture of coal-gas and air, between about 50 and 500 volts. In the same figure are also shown

similar relations for alternating current, one being for a non-inductive and the other for an inductive circuit, the frequency being 40 cycles per second and the sparking poles being of copper.

As previously noted the character of the alternating-current curves is different from those for continuous current, and for a given voltage the amount of the current is always higher. Fig. 5<sup>\*</sup> shows how at a fixed voltage (90 volts) the least current capable of producing an igniting spark in an 8 per cent mixture of methane and air varies with the inductance of the circuit. It is interesting to note that in an inductive circuit at relatively low voltages the

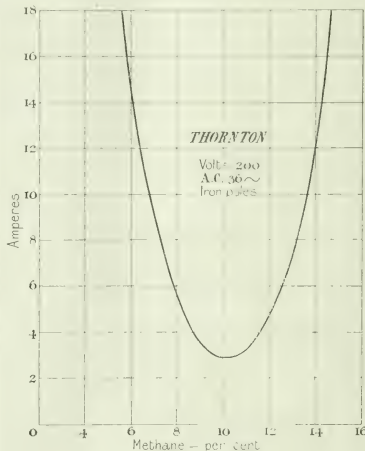


FIG. 4.

current varies but little over a wide range of voltage variation. An example is shown in Fig. 6.<sup>†</sup> A similar condition is found in Figs. 8 and 10. The curves given in Figs. 1, 5, and 6 all show that the amounts of voltage and current, or current and inductance, capable of producing dangerous sparking are comparatively small, and emphasize the necessity, already well known, of adequately safeguarding electrical apparatus to which explosive gases are accessible.

The experiments upon which the curves in Figs. 1, 5, and 6 depend were performed with the aid of single sparks. When a given spark was of the intensity just below that required for ignition it was reproduced a number of times, and if ignition was never obtained the spark was regarded as ineffective in the particular gas employed. It is permissible therefore to assume that, taking an example from any curve in Fig. 1, any value of

\* Home Office Report on Battery-Bell Signalling Systems. *Anle.*  
† *Ibid.*

current below the curve could not produce a spark capable of igniting the gas. It must be borne in mind, however, that the repeated sparkings which were found by the experimenters to be incapable of igniting the gas, were produced at a comparatively slow rate by rotating one of the poles by hand or a small motor, and unless this fact be noted the above assumption is liable to be misleading. The author finds that a single spark which when repeated

manipulation would permit; but when the trembler was allowed to vibrate normally, ignition due to the trembler spark occurred after 1 second. At 5 volts ignition occurred after 10 seconds. This fact appears to be of practical importance in connection with that system of bell signalling commonly used in mines, in which the circuit is closed by the application of a piece of iron to a pair of bare wires. Sometimes an old file or a knife is used, and whatever be the implement employed the surface is usually rough. In drawing this implement across the wires there is not obtained the single spark of carefully maintained laboratory apparatus, but a rapid succession of sparks approximating to that of the trembler.

Reverting now to the question as to whether the measure of the circuit volts and amperes, or amperes and inductance, can be regarded as a measure of the incendency of the spark, Professor Thornton has stated that the energy of a break-flash (referred to sometimes in this paper as a single spark) is proportional to the power of the circuit and is equal to  $\frac{1}{2} L i^2$ , where  $i$  is the circuit current.<sup>6</sup> In a recent leading article the *Electrical Review*<sup>†</sup> has gone a step further. Arguing from Professor Thornton's work and basing its

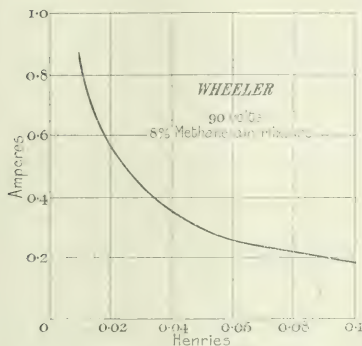


FIG. 5.

slowly will not ignite a gas, will after a more or less definite interval produce ignition when repeated rapidly. The element of time seems to him to be a factor of importance in ignition phenomena. If instead of a single-break device a vibratory make-and-break device (such as the trembler of a bell) be employed, it is found that the ability of a given spark to ignite a gas mixture depends upon the

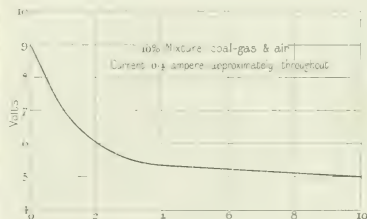


FIG. 7.

calculations specifically on certain curves by Dr. Wheeler (of which Fig. 5 is one), it is stated that the igniting power of a break-flash depends on the  $L i^{2.5}$ , or approximately the  $L i^{1/2}$ , of the circuit. Finally it is stated that for every gaseous mixture there is a constant value of the product  $L i^{1/2}$  beyond which the break-flash will be capable of igniting the mixture. This is an interesting deduction, but the truth does not seem to be expressible in such a simple form. Igniting sparks can be produced in practically inductionless circuits carrying but a few amperes. These sparks, which may be termed "hot-point" sparks, are not included in an expression based on inductance.

When a pair of contact points in a non-inductive circuit are separated so that an arc is maintained between them it is true that the product  $vi$  is a measure of the power of the arc. The value of  $vi$  is not necessarily the same during arcing as when the contacts are together, and there is no reason for assuming them to be the same when the arc is only of momentary duration. Therefore  $vi$  prior to sparking is not a measure of the power of a hot-point

duration of the sparking as well as upon the circuit conditions recorded in the investigations above described.

Fig. 7 shows a typical result following the use of a trembler spark in an explosive atmosphere consisting of a 10 per cent mixture of coal-gas and air. The current was approximately 0.4 ampere throughout the range of the experiment. At 9 volts ignition was obtained instantly. On reducing the voltage to 7 a single break-spark would not ignite the gas, even when repeated as rapidly as hand-

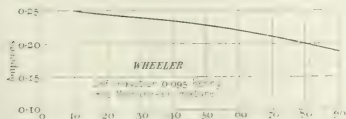


FIG. 6.

<sup>6</sup> W. M. THORNTON, "The Least Energy required to Start a Gaseous Explosion," *Philosophical Magazine*, vol. 28, p. 734, 1914.

<sup>†</sup> *Electrical Review*, vol. 77, p. 95, 1915.

spark. Further, in non-inductive circuits carrying the same power both igniting and non-igniting sparks can be produced by simply altering the shape or material of the contacts. Again, when the circuit is inductive and the above effect does not enter or is negligible, then the energy which produces the spark on separating the contacts is expressed by  $\frac{1}{2} L I^2$ . With the same energy either igniting or non-igniting sparks may be produced according to the shape or material of the sparking points.

As already indicated, curves connecting volts and amperes, or amperes and inductance, in the circuit are useful as giving a general idea of the magnitudes involved in the production of igniting sparks, but caution must be exercised in using them, since (1) a variation of the size or material of the sparking points is attended by an alteration of the value of the circuit current required to produce an igniting spark, and (2) the incendency of a spark depends to some extent upon its duration.

The general conclusion to which the author has been led by a variety of experiments on the electrical ignition of gases is that it is necessary to distinguish between the energy which produces a spark and that quality of the spark termed by him "incendency" which enables the spark to cause ignition, and that the magnitude of the one is not a measure of the other although there may be a more or less regular relation between them when certain physical conditions are kept constant. Ignition seems to depend on the ionization caused by the spark. During the interval of sparking the ionization may be rapidly dissipated or neutralized. If the neutralizing action predominates there is no ignition of a gas mixture. If there is little or no neutralizing action ignition occurs immediately. Between these two limits there are a variety of intermediate conditions, which apparently account for the delay of ignition indicated by Fig. 7 and much of the great irregularity that is often experienced in experimental work on this subject.

The foregoing remarks describe the main features of the theory of ignition by sparks so far as it relates to electrical apparatus for mining and other operations in which an explosive atmosphere is liable to occur. As already stated, the outstanding fact of practical importance is that circuits carrying relatively small amounts of electrical energy are capable of producing dangerous sparks. No fact is more familiar, and at this date no justification could be found for addressing to electrical engineers a paper on the subject of gas ignition by sparks were it not for the existence in many mines of a crude but indispensable piece of apparatus—the electric-bell signalling circuit—which in consequence of at least one serious disaster has excited the suspicion and attention of those responsible for the safety of mines and caused a revival of enquiry into the facts associated with spark-ignition.

The prevention of ignition by sparks in the power and lighting circuits of mines has been thoroughly investigated, and, excepting accidental breakage of cables, no danger need be apprehended if the usual protective devices are maintained in proper condition. The open sparking on the bare wires of the bell systems has, however, been neglected, and an urgent necessity has arisen to render it harmless. Before dealing with this subject a brief digression may advantageously be made on the protection of enclosed apparatus.

#### ENCLOSED APPARATUS.

In a paper by Mr. S. A. Simon\* an interesting account is given of an investigation carried out by the Committee of the Westphalian Mining Fund and six leading electrical manufacturers in Germany, to determine the value of totally enclosing apparatus as a protection against explosion. Among other things mentioned is the effect, upon the pressure attained in an explosion within an enclosing case, of the configuration of the case and the rotation (when this occurs) of the parts enclosed.

Various experiments have been made by different investigators into the effect on an explosion of the shape of the gas-containing chamber, and it has generally been found that whilst with cylindrical and spherical chambers the shape does have a modifying effect, it is not sufficient to be of any practical importance in the design of a case. The German investigation rightly emphasizes, however, the important fact that if the shape is such that the case virtually comprises two or more communicating compartments, then an explosion initiated in one of them might spread to and produce destructive effects in the other. Another fact is that a given gas mixture which explodes harmlessly in a motor case when the armature is at rest might explode with sufficient violence to wreck the case when the armature is in motion.

These phenomena are quite well known in connection with the study of gas explosions. The increased pressure in the first is due to compression prior to ignition, and in the second is due to turbulence. Both are operative in the working of an internal-combustion engine, and although the effect of the first has been familiar for many years, it was not until recently that the importance of the second was discovered.† It is now known that the gas or petrol engine is largely dependent for its action upon the state of commotion of the gas immediately prior to ignition. In the design of protective cases for electrical apparatus it is necessary (1) to avoid intercommunicating chambers or chambers with partitions so arranged that it is possible for an explosion in one chamber to compress the gas in the other before igniting it, and (2) to construct the case so that it will withstand the increased explosion pressure due to turbulence. Theoretical investigations seem to show that the maximum pressure attained is but little affected by turbulence, although the speed with which the explosion attains its maximum pressure is greatly accelerated. Mr. Simon mentions, however, that a motor which successfully resisted an internal gas explosion when at rest had its cover blown off by an explosion when the motor was in motion. At first sight this does not appear to agree with what is known of turbulence effects; but the explanation is probably that when an explosion occurs in a chamber in which the cooling surface is relatively large, turbulence may produce not only an increased rate of explosion but also an increased maximum pressure. A further fact which might have a practical bearing upon the design of covers is the character of the internal surface, if the configuration involves restricted passages. A rough surface has an accelerating effect both in dust and gas explosions,‡

\* S. A. SIMON, "Notes on Safety of Working Electrical Plants in Coal Mines," *Journal I.E.E.*, vol. 43, p. 107, 1909.

† DUGALD CLERK, *Gustave Candel Lecture*, 1913.

‡ (1) *Blue Office Reports of Explosions in Mines Committee*, No. 4. (2) J. D. MORGAN, "Coal Dust Explosions," *Transactions of the Institution of Mining Engineers*, vol. 49, p. 220, 1915.

probably due to turbulence. Whether this effect is appreciable in closed chambers does not appear to be definitely known, but in tubes the effect is very marked.

#### MINE BELL-CIRCUITS.

As previously mentioned, the signal bell-circuits employed in mines commonly comprise a pair of bare wires connected to a trembler bell and battery. A signal is given by connecting the wires with the aid of a metal instrument such as a file, a knife, or an iron bar. The bare-wire system has much to commend it on the score of simplicity and convenience, but latterly it has become the subject of much suspicion, especially since the Senghenydd disaster in 1913. The danger associated with bare signal wires has, in the author's opinion, been somewhat exaggerated; nevertheless some danger does exist, and it is well that the risk should be eliminated. Suggestions have been made to

in the interpretation of a signal is less with the trembler than the single-stroke bell.

Danger of gas ignition at the trembler has been minimized by the use of an enclosing case, and the risk due to the spark in the external circuit has been tolerated partly for the reasons that such spark is supposed to be comparatively harmless and that the ventilation of the mine is sufficient to prevent the accumulation near the wires of an explosive mixture. Laboratory investigations show that using a bell of the ordinary type the break-spark can be not less dangerous than the trembler spark. If it is deemed necessary to enclose the trembler there is no justification therefore for disregarding the break-spark. The first necessity is to abolish the break-spark or reduce it to harmless dimensions, and the second is to render impossible such a variation of the bell adjustment as would enable a dangerous break-spark to be produced.

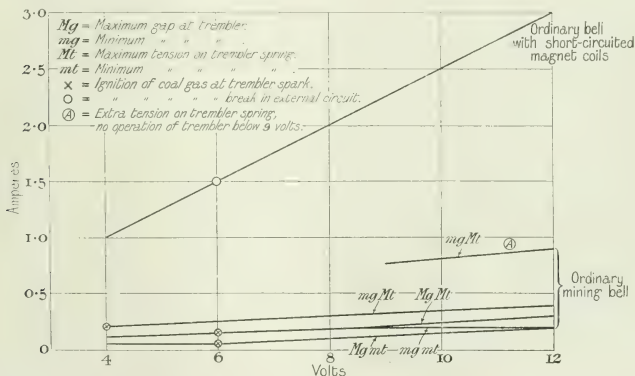


FIG. 8.

abolish bare-wire circuits and employ enclosed switches arranged at suitable intervals along insulated circuits, but the inconvenience of this is sufficiently evident to make it clear that miners will not abandon the bare-wire system unless it is shown to be irremediably dangerous. The facts appear to be that the system is not seriously risky and that what risk does exist can easily be removed. A very careful investigation of the subject has already been made by Dr. Wheeler,\* and his Report contains valuable suggestions of a simple and practical nature.

The spark at the trembler of a bell is rightly regarded in a general way as more dangerous than the single break-spark which occurs on the bare circuit when a signal is given. To avoid the use of a trembler it has been proposed to use single-stroke bells; but the trembler bell is apparently preferred by miners, as the liability to mistake

The results of tests by the author on a mining bell in an atmosphere of coal-gas are shown in Fig. 8. One object was to find the variation of current in the bell circuit with variation of voltage, and the manner in which these variations are affected by alterations of the bell adjustments. The other object was to find with what voltage and current ignition could be obtained both at the trembler and the break or contact in the external circuit. By adjusting the movable contact-screw at the trembler so as to produce the minimum spark-gap when the armature was vibrated by the magnet, and reducing the resistance of the armature controlling-spring to the minimum, the relation of volts and amperes indicated by  $mg,mt$  was found. At 4 volts the current was 0.1 ampere, and at 12 volts the current was 0.2 ampere. Retaining the same tension at the spring and increasing the trembler gap to the maximum, the curve  $Mg,mt$  was obtained. With this adjustment the current is 0.05 ampere at 4 volts and

\* R. V. WHEELER. Home Office Report on Battery-Bell Signalling Systems, 1915.

0.2 ampere at 12 volts. Keeping the gap at the maximum and increasing the spring tension to the maximum at which the bell could be actuated with a pressure of 4 volts, the relationship between volts and amperes is given by the curve Mg.Mt. in which the current rises



FIG. 9.

from 0.1 ampere at 4 volts to 0.3 ampere at 12 volts. Still keeping the maximum tension, but adjusting the gap to the minimum, there was obtained the curve mg.Mt. which varies from 0.2 ampere at 4 volts to 0.4 ampere at 12 volts. A much higher current could be passed through the system by largely increasing the spring tension, but the bell could not then be actuated at a pressure below 9 volts. The result is shown in the short upper curve which rises from 0.75 ampere at 9 volts to 0.9 ampere at 12 volts.

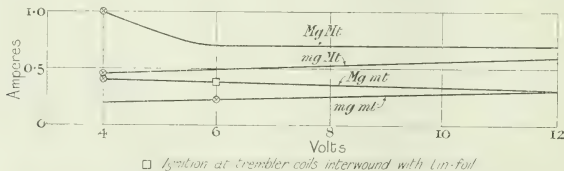


FIG. 10.

Experimental Coil.—Two coils, 102 turns, 28 S.W.G. copper wire each coil. Platinum sparking tips 2 mm. diameter

Repeating the above experiments in order to determine the conditions necessary for ignition of a coal-gas mixture, it was found that in the tests corresponding to the first three curves ignition could be obtained at 6 volts, but not lower; whereas when the spring tension was increased and the gap diminished as above stated, ignition could be obtained at 4 volts. It is necessary to note that when the gas could be ignited at the trembler spark it could also be ignited (although sometimes only after a number of trials) at the single break-spark. In these tests, therefore, both sparks were equally dangerous. It is also necessary to note that the system which could be made to operate safely below 6 volts could be rendered dangerous by altering the trembler spring.

The above remarks are only true for coal-gas. It may be rather severe to test a mining installation in coal-gas, but if it can stand the coal-gas test it is abundantly safe in methane. An ignition test made by Dr. Wheeler on the above bell showed that with the armature fixed and the trembler contacts touching (a condition which gives the largest break-flash), the least current required to pro-

duce an igniting break-flash in an 8 per cent mixture of methane and air was 0.26 ampere at 25 volts. An oscillogram of the current taken by the bell while ringing has been kindly supplied by Dr. Wheeler and is shown in Fig. 9.

To ascertain whether a large reduction in the strength of the magnet coils would reduce the capability of the trembler and break-sparks to ignite coal-gas, a pair of weaker coils was arranged in conjunction with a vibrating armature contained within a small explosion chamber, the armature being controlled by a spiral spring instead of the flat or blade spring usually employed in bell construction. The results of tests are shown in Fig. 10. In all cases the current values are higher and the sequence of the curves is slightly different from that of the bell tests. With minimum gap and minimum tension, ignition was first obtained both at the trembler and the break at 6 volts. With the other adjustments ignition was obtained at 4 volts. It follows, apparently, that it is useless to reduce the inductance of the circuit to avoid dangerous sparking unless the value attainable by the current is also reduced. In his report Dr. Wheeler remarks upon the desirability of making the resistance as high as possible, and the above experiments support this conclusion.

An obvious deduction from the foregoing is that for safe working the maximum voltage should be kept as low as possible. In the author's opinion the value permitted by

the Home Office Regulations, namely 25 volts, is much too high. Also the internal resistance of the batteries should be high in order to avoid a relatively large current in the event of an accidental short-circuit. Further, some additional precaution should be taken to abolish the spark or to reduce it to negligible dimensions.

A variety of expedients have been devised. One, well known to telegraph engineers, consists in the arrangement of a non-inductive shunt of comparatively high resistance across the ends of the magnet windings. This diminishes the trembler spark and probably reduces the break-spark. A condenser across the trembler gap improves the conditions at the trembler, but does not remove the danger from the external circuit. Another device consists of a short-circuited winding or layers of tin-foil between the magnet windings for the purpose of reducing the energy available for sparking at the gap or break. Layers of tin-foil were wound in the magnet windings of the coils used for the tests recorded in Fig. 10, and it was found that whilst they increased the voltage required for ignition at the trembler from 4 to 6 in the Mg.mt.

curve, no improvement was found at the break-spark of the external circuit.

An arrangement which has been found to give good results at both the trembler and the break is shown in Fig. 11. The action at the trembler is the reverse of the



FIG. 11.

ordinary action. Instead of interrupting the circuit, the trembler short-circuits the magnet. The magnet windings are indicated by *a* and the spring-controlled armature by *b*. One end of the armature is connected to one end of the magnet coils, and the fixed contact *c* is connected to the other end. When the external circuit is closed as indicated diagrammatically at *d*, the magnet is excited and the armature is attracted by the same. Near the end of the movement a spring blade *e* on the armature touches the fixed contact *c* and short-circuits the magnet. By means of its spring the armature is returned, and the parts *c* and *e* are separated. The action is then repeated and a vibratory motion of the armature is obtained. Only a very minute spark is produced at the trembler, and this is entirely negligible. The intensity of the single break-spark at *d* is not reduced, however, to the same extent, and although it is much less active than when the ordinary trembler construction is used in the bell, it is possible to produce ignition of an explosive coal-gas mixture.

The mining bell above referred to was converted, without altering the magnet coils, to correspond to Fig. 11, and the result of a test is shown by the top line in Fig. 8. It will be observed that the current taken by the bell was very considerably larger than that by the normal bell. At 4 volts the current was 1 ampere, and at 12 volts it was 3 amperes. Notwithstanding the relatively large amount of current no ignition of a coal-gas mixture could be obtained with any voltage at the trembler, but ignition

could be obtained with 6 volts at the external break. By suitably proportioning the magnet windings and inserting a resistance between the battery and the bell, the current can be reduced to something of the same order as that required for an ordinary bell, and in that case the external circuit would be rendered quite safe.

Notwithstanding the improvements obtainable by devices such as those above described, the complete solution lies, in the author's opinion, in a suitable relay system. By using a small relay arranged to be actuated by a 4-volt battery he obtained perfect operation of the bell with a current of 0.1 ampere in the relay circuit. Sparking in the external circuit of the relay was quite insignificant and no ignition of coal-gas could be obtained. It was necessary to increase the relay current to 0.6 ampere before ignition could be produced. At the relay contact the condition was the same as in the external circuit of an ordinary bell; but it is obvious that this could be avoided by the use of a condenser or non-inductive resistance at the relay contact and the employment of a short-circuiting trembler at the bell. A similar experiment to the foregoing was performed by Mr. Watts<sup>9</sup> with similar results. Under laboratory conditions there is no difficulty in rendering a bell system safe on the lines above indicated, and there appears to be no reason why the same conditions cannot be realized in a practical apparatus suited for mining conditions.

#### CONCLUSION.

The opinion has already been expressed above that the Home Office Regulations limiting the highest permissible voltage in bell signalling systems to 25 cannot secure safety, as the figure is obviously too high. If it is desirable to fix a limit, the figure should be reduced to 6. With the adoption of a relay system this lower figure is practicable. The fixing of a voltage limit is not, however, sufficient in itself to ensure safety. There should be added the condition that sparks produced in the system should not be capable of igniting a specified mixture of methane and air, as this result is easily obtained with a relay.

<sup>9</sup> T. G. WATTS. "Investigations into a System of Electric Bell Signalling for Use in Collieries." *Proceedings of the South Wales Institute of Engineers*, vol. 30, p. 529, 1914; and *Electrical Review*, vol. 76, p. 30, 1915.

#### DISCUSSION.

Professor G. KAPP: The subject of the paper is of extreme practical importance, but also of considerable difficulty because there are so many elements which affect the condition of what the author calls incendivity. We are told that even X rays without any spark can produce ignition and also a brush discharge without flashing over. Conditions of this kind are not likely to occur in a mine, and the author has limited the investigation to the conditions which one would naturally regard as determinant on the question of ignition, namely the voltage, current, and power in the spark. One thing stands out clearly in the paper and that is the greater safety of alternating currents. This matter has, however, more direct reference to the question of machinery and I do not propose to enter into it here, since it is sufficiently known. The point on which I venture to make some remarks and a suggestion is in

connection with signalling bells. The author says on page 198 that "the energy associated with a circuit prior to sparking can be regarded as a measure of the incendivity of the spark." If the author means that the sentence should be read with the tacit understanding that the electrical conditions of the circuit remain unchanged and only the energy is raised by increasing the voltage, then I agree. The same idea also underlies his suggestion that the maximum voltage as fixed by the Home Office should be reduced. I submit, however, that it is not the energy alone, but also the means employed to dissipate it, which should be regarded as essential factors of the problem. He mentions certain expedients which are intended to assist the dissipation of energy. When the current is interrupted the stored energy  $LI^2/2$  must go somewhere; either into the shunt resistance, or into the damping

Professor Kapp.

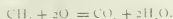
Professor  
Kapp.

wrappers of tinfoil, or into a condenser, but it is questionable whether a condenser is practicable. It would have to be fairly large if it is to be effective with the magnetic circuit of a bell. The use of an inductionless shunt to the exciting circuit of the bell is objectionable because it increases the line current and therefore the sparking at the bare mine wires when bridged. The author's device of working the bell on what may be called an inverted principle seems much preferable, and to judge from the results of tests given in the paper this principle is quite successful. Thanks to the author's ingenious device the problem may be considered solved at the bell, but what about the danger of incendivity of the spark when contact is made and broken at any point along the two bare wires which the author tells us miners will not give up? On page 201 the author says that "the break-spark can be not less dangerous than the trembler spark," and to meet that danger he suggests later on in the paper a relay system where the break-spark would naturally be that of a very feeble current and therefore innocuous under all circumstances. No doubt a relay system would be a solution, but is it robust enough for the rough usage of a mine? I suggest that perfect safety might be obtained in a simpler manner by distributing condensers along the signal wires and especially putting one at the tail end. This expedient has the advantage that it can be applied to any existing installation at very little cost. By using Mansbridge condensers the cost of 10 or even 20 mfd. to each kilometre of line would be quite trifling, and the mechanical protection of such a condenser presents no difficulty. To show what the effect of thus ballasting the line with condensers would be, I have calculated the sparking conditions of a particular line with and without condensers. The line is a mile long and consists of two wires spaced 10 cm. apart. Its inductance is 2.6 millihenries, its capacity a little over 0.01 mfd., and its resistance 20 ohms. Suppose a current of 1 ampere is broken at the tail end. We get an oscillation with a periodic time of 34 micro-seconds, the damping effect of the resistance being very small. During the fraction of a second that it takes to remove the iron bar by which the signal has been given, there may be some thousands of oscillatory sparks passing between wire and bar. The electromotive force at the moment of zero current will be 440 volts, and the maximum power which occurs at the time of 4 micro-seconds after the break is 200 watts. It is true that the total energy stored in this so-called "non-inductive line" is only about 1,300 micro-joules, but the frequency is extremely high and the author has told us that high frequency increases the danger. It is therefore quite conceivable that a current of 1 ampere broken anywhere on this line may produce a dangerous spark. Now let us ballast this line with only 10 mfd. in all, evenly distributed, say in quarter-mile sections. The frequency of the spark has now decreased to 1,000 per second, the maximum voltage to 4.4, and the maximum power, which occurs 125 micro-seconds after breaking, has fallen to very little over 2 watts. These figures are well within the limits set by the author and I should be glad to hear from him in his reply whether he considers my suggestion practicable and effective.

Dr. C. C. GARRARD: The author has continued the experiments made by other investigators to determine the

maximum possible safe spark. I should like to know Dr. Garrard whether he would agree with me when I say that the general conclusion which he has reached is that electric sparks in contact with the atmosphere of a mine under all conditions are dangerous and should be avoided. In this connection I am reminded of an experience we had some years ago when a member of the Institution read a paper to show that the respect, from the point of view of danger to life, in which 500-volt traction circuits had been held was unfounded, that overhead tramway trolley-wires were quite safe to handle, and that many of the restrictions governing the use of overhead wires could be done away with. Immediately after the paper was read several people were electrocuted by a falling trolley wire. In the same manner a year or two ago we had reached the conclusion that sparks from the bell signalling circuits in mines were quite harmless, and then the disaster at Senghenydd occurred. The suspicion that it was due to sparking caused by electric signalling has caused us to modify our views on the matter. My own view is that all electric sparks in collieries should be regarded as dangerous and should be enclosed in suitable boxes. This brings up the question as to what is a suitable box for containing apparatus which may spark. The Home Office Regulations (General Regulation No. 132) specify that in any part of a mine in which inflammable gas, although not normally present, is liable to occur in quantities above  $\frac{1}{2}$  per cent, all apparatus shall be constructed so that "in the normal working thereof there shall be no risk of open sparking." Although the term "open sparking" is defined by the Regulations as "sparking which owing to the lack of adequate provision for preventing the ignition of inflammable gas external to apparatus would ignite such inflammable gas," I cannot but think that the term is misleading. The ordinary person would surely think that open sparking is sparking which one can see, and that any kind of iron cover would be sufficient. This, however, is of course not the case. It is interesting to consider how this term of open sparking has been arrived at. Originally we used to speak of gas-tight switchgear. This term has fortunately been discontinued. The terms "explosion-proof" and "flame-tight" are still, however, in general use. The United States Bureau of Mines applies the term "explosion-proof" in the same sense as our own regulations use the term "freedom from open sparking." In my opinion a switchbox for use in a colliery should be both explosion-proof and flame-tight, *i.e.* capable of withstanding any internal explosion without emitting flames or sparks which would ignite an explosive mixture outside the box. Reverting again to the limit of inflammability, there are two other points which the author has not touched on. The presence of ethane increases the liability of explosion of methane and air mixtures. The presence of coal dust is also of importance. It has been found that with sufficient coal dust an explosion can be caused by sparks in an atmosphere containing only  $\frac{1}{2}$  per cent of gas. These facts strengthen the arguments for the total abolition of open sparking in collieries. I think the author's remarks as to how ignition depends on the ionization caused by the spark are very illuminating, and if this point be followed up I have no doubt many mysterious facts will be elucidated. I am also much interested in that portion of the paper which deals with the maximum pressure that may

ard. occur inside enclosed apparatus. Especially am I interested in the possibility of the violence of an explosion being increased by a portion of the explosive mixture within the box becoming compressed before ignition, due to an explosion in another part of the same box. I should like to know whether the author can tell us the maximum possible pressure which can exist inside an enclosed box due to an internal explosion. If we consider the combustion of methane we obtain the following equation:—



It will be seen that three molecules of gas disappear, and while the water formed remains gaseous three are formed. Thus the violence of the explosion is simply due to the heating up of the gases. It is obvious that if the water can be condensed as quickly as it is formed, due to the rapid cooling of the products of combustion, by means of a heavy box of large cooling capacity, the violence of the explosion must be greatly reduced. Coming to the question of mining bells, the author advocates that if the system of bare contact wires is to be retained sparking must be entirely removed from them. He states that this may be done by means of a relay. I can confirm this. By means of a relay combined with a condenser it is possible to suppress entirely the spark at the signalling wires. The only question then arising is that if anything should go wrong with the adjustments of the relay, sparking might still occur at the signal wires. I am therefore inclined to think that a mechanical pull arrangement, with the contact-making device enclosed in an explosion-proof and flame-tight box, will eventually replace the bare signalling wires hitherto used.

ng. Mr. A. P. YOUNG: I am chiefly concerned with the problem of ensuring that an explosion will result from an electric spark, but nevertheless this paper, which deals with the opposite problem, possesses many points of very great interest to me. The first portion of the paper in which the author puts forward evidence to show that the origin of an explosion resulting from an electric spark is probably more ionic than thermal, opens up a very wide field for thought and investigation. Ignition by means of an electric spark is now almost generally adopted, and it may be that the great success of this method is due, in some measure, to the fact that the electric spark—by virtue of its very nature—possesses some subtle power of causing an explosion, quite apart from the heating effect that occurs at the points of the sparking plug during the discharge. The various curves reproduced in the paper relate to inductive and non-inductive circuits carrying alternating or continuous current, the current and voltage being adjusted in each case so that on breaking the circuit the spark is just sufficient to cause an explosion of the gaseous mixture being investigated. The curves connect the current flowing in the circuit before break, with the voltage applied, but do not give any indication of the actual amount of energy dissipated in the spark at the point of break. In the case of an inductive circuit carrying continuous current, it is easy to see that the energy appearing in the spark is the amount of energy stored electromagnetically in the inductance, and should therefore amount to  $LI^2/2$ . With a continuous-current non-inductive circuit the energy cannot be calculated in this way, and I should like to have the author's views as to how

it can be arrived at. It obviously bears no definite relation Mr. Young. to the power of the circuit before the contact points are separated, and it would seem to be dependent upon the rate at which these points move apart during the short interval of time in which the spark occurs, as the duration of the spark would, I imagine, be dependent on this rate of movement and also on the material of which the electrodes are made. It seems to me that one is chiefly interested in the energy dissipated in the spark when considering the efficacy of the spark to produce an explosion, and I am of the opinion that it would have been very much better if the various experimenters referred to had plotted an energy curve showing exactly how the energy of the spark producing an explosion varied with the percentage of methane present in the mixture. In the case of a magneto the firm with which I am associated have carried out numerous oscillograph experiments which prove conclusively that the high-tension spark is unidirectional, and I should very much like to have the author's opinion as to whether a unidirectional spark is more efficacious in the production of an explosion, as compared with an oscillatory spark, other things being equal and assuming that in each case exactly the same amount of energy is dissipated during the discharge. The author states that "the incindivity of a spark depends to some extent upon its duration," and I should be greatly interested to know whether he can give any definite information bearing on this particular point. In other words, assuming that between certain electrodes a definite amount of energy is dissipated during a discharge, would the explosive power of the spark be affected by varying the time during which this discharge occurs? Dealing in particular with the petrol motor, various writers on the subject of "Ignition" seem to differ as to the minimum amount of energy required to produce an explosion in a cylinder, and I should very much like to know whether the present author has any definite data bearing on this point. I might say that calorimetric tests made on high-tension magnetos show that the energy is in many cases as high as 0.2 joule, but on the other hand there are many magnetos on the market which appear to give satisfactory ignition, and yet which have an energy output very much less than this figure. Leaving the question of ignition, and dealing particularly with the method of signalling adopted in mines, it seems to me that the trouble due to sparking at the points where the miner makes contact with the two wires, could be overcome to a great extent if a resistance were permanently connected between these two wires, this resistance being so adjusted that the current flowing continuously through the bell-circuit is not sufficient to operate the bell. To obtain a workable arrangement it might be necessary specially to design the magnetic circuit of the bell so that the armature would be in a perfectly stable condition even when the value of the current flowing through the operating coils was a large percentage of the current required to operate the bell. With such an arrangement the miner when connecting the two lines by means of a file or other metal part, would short-circuit this resistance and ring the bell, but when he again removed the file or metal part, the points at which sparking normally occurs would be linked to the ends of this resistance, and in that way the sparking would be very considerably reduced.

Dr. Railing.

Dr. A. H. RAILING: If only the main question as to what is the process of ignition could be answered much that is now obscure would immediately be made plain. I suggest that the process may be somewhat as follows:—An explosive gas mixture contains atomic or sub-atomic constituents which by reason of their affinity are capable of combining and in so doing produce the phenomena of an explosion. Under normal conditions this affinity is too feeble to permit of combination and requires the operation of some agency to make it effective. Just as molecular turbulence is capable of speeding up a reaction, so some kind of atomic or sub-atomic turbulence might be necessary to start the reaction, and this turbulence might be produced either by heat or by ionization. I consider that an investigation of this idea might bring about a reconciliation of the ionic and thermal theories of ignition which at present appear to be opposed.

Mr. Watson.

Mr. E. A. WATSON (*communicated*): The amount of energy required to ignite an explosive mixture is a subject of great importance, not only from the point of view of the danger of unintentional explosions, as for instance in collieries, but also from that of the production of ignition in the cylinders of internal-combustion engines. The numerical value of the necessary energy is a quantity which is very far from being definitely laid down, as an examination of the different systems of ignition in use will show, and indeed it seems that with our present knowledge of the mechanism of the propagation of an explosion we cannot hope for any hard-and-fast limits for this figure. The experiments quoted by the author, proving that the phenomenon of combustion is not altogether a thermal one, but is to some extent at any rate a question of ionization, seem to show that the problem of whether a given spark will or will not ignite an explosive mixture is not altogether a question of the total amount of energy available. On the thermal basis of ignition it is comparatively easy to see how it may be possible for there to be a limiting value to the energy below which ignition will not occur. If we consider a small quantity of hot burnt gas surrounded on all sides by a shell of cold unburnt explosive mixture, ignition will only occur if the heat liberated by the burnt core is sufficient to raise the surrounding shell to its ignition temperature. The smaller the volume of the hot core the less will be the ratio of the volume of core to the area in contact with the surrounding shell and the greater the cooling effect. We should therefore expect that before ignition of the whole charge could occur it would be necessary to raise a definite volume of gas to the ignition point, and this would of course require a definite amount of energy. We should further expect that the value of the minimum energy required would be affected by the pressure, and certainly by the temperature of the explosive mixture before ignition. It would be very interesting to know if any experiments have been made which give any information upon this point. There is little doubt that the temperature of the mixture before ignition has a very great bearing upon the energy required. Every motorist is aware that it is easier to start an engine which is already warm than one which is cold, and although the difference is doubtless to a large extent one of carburation it may also be in part due to the smaller amount of energy required. Furthermore, the fact that, as mentioned in the paper, although one spark will not ignite a given

mixture yet a rapid succession of sparks will do so, might quite well be due to the heating of the mixture by the energy liberated. In this connection it is interesting to note the very large range of variation in the energy of the spark given by different makes of magnetos now on the market, all of which may be said to give satisfactory ignition of the explosive charge. The output of a magneto varies considerably with the speed, but taking a standard speed of 500 r.p.m. it is found that the energy per spark given by various single-cylinder magnetos varies from 0.007 joule for a small American magneto to as much as 0.005 joule for a high-class English machine intended for very similar duty, i.e. a range of output of very nearly 10 to 1. It would therefore seem that either the one machine must be unsatisfactory or the other must be needlessly powerful; and undoubtedly a great deal might be done in the matter of deciding upon the minimum energy which would give satisfactory ignition. The problem is, however, complicated, as much probably depends upon the speed of the engine, it being quite conceivable that an amount of energy which would be sufficient for a low-speed engine may be inadequate for a high-speed one. In fact the problem of how the horse-power given by an engine depends—other conditions remaining the same—upon the energy given by the magneto is one which would well repay investigation. It is a well-known fact that a substantial increase in the brake horse-power may be obtained in most large high-speed engines by igniting the charge simultaneously at two points in the cylinder, and this is sometimes done—especially in aeroplane practice—but there appear to be no data available to show whether an increase in brake horse-power might be obtained by increasing the energy at the sparking plug. Some rough experiments made on a comparatively small low-speed gas-engine with a magneto fitted with an electromagnet, the excitation of which could be varied at will, gave a negative result, since, provided that the excitation was sufficient to cause a spark to jump the plug at all, no improvement was obtainable by a further increase in energy. The experiments were, however, only very rough and cannot be considered as being at all conclusive. In any case the effect, if any, would probably be most marked at high engine-speeds. It is hoped to carry out some experiments on this point in the near future, but it is certainly a question on which information is desirable.

Mr. Wall.

Mr. S. F. WALKER (*communicated*): I claim to be one of the earliest pioneers of electric signalling in mines. Quite 25 years ago the question arose whether the spark on breaking circuit after ringing, by pressing the naked iron wires together, would ignite gas, and I therefore made some very exhaustive experiments from which it appeared that there was very little chance indeed of ignition taking place. My experiments were confirmed by the officials of the Wigan Coal and Iron Company previous to my installing some signals at one of their collieries; the experiment being undertaken by the direction, and I believe under the personal supervision, of the managing director, Mr. W. H. Hewlett. For the signals which I fitted in mines single-stroke bells were almost universally employed. My view, which was confirmed by the mine managers at the time, was that the single-stroke bell properly adjusted gave very clear distinct signals, while the trembler bell did not and could not. I believe the

single-stroke bell was displaced by the trembler bell later on, because a number of very cheap trembler bells were placed upon the market; the original cheap trembler bells were, I believe, of German make. With single-stroke bells the danger of ignition of gas by sparks is considerably reduced, since I think it is acknowledged that there is very much less danger from the spark that passes on breaking circuit after ringing by pressing the two iron wires together, or by making connection between them in any other way, than from the spark at the contact of a trembler bell. One of the difficulties that has always arisen in connection with engine-plane signals in coal mines is that the wires are apt to get dirty. In damp mines, moisture deposits upon the surfaces of the wires and a thin deposit of coal dust follows, with the result that it is necessary practically to scrape the wires when making connection between them in order to make the bell ring. I suggest that a return to the single-stroke bell would considerably reduce the danger from the use of electric signals. For complete immunity I am afraid that naked wires will have to be given up, and that the connection for ringing will have to be made in explosion-proof cases. I have been particularly impressed by the fact which the author has brought out, that a continuance of either a spark or a brush discharge changes the nature of the air between the points across which sparking or discharge is taking place, and that after a certain time ignition follows. I suggest that what takes place is that the air between the points has its temperature raised. I think it is well known that sparks will pass and arcs form more easily in air the temperature of which has been raised. I am particularly interested in the suggestion which the author makes at the end of the paper, that relays should be used with batteries of small pressure. About 35 years ago I adopted this very system at the Nunnery Colliery, Sheffield, but for a totally different reason. A signal was fixed on a very long engine plane which was also very wet, and the leakage was so great that batteries would only keep up to their work for a very short time. As I had to maintain the batteries for a certain time after the signal was fixed, and then by contract for a comparatively small annual payment, the matter promised to be rather serious. Obviously, increasing the battery power increased the trouble. Temporary relief was obtained by increasing the size of the cells, but the trouble was not finally overcome until I adopted the method which the author proposes. I divided the battery into two; I think 20 Leclanché No. 1 cells worked the bell originally. I fixed a relay and used only six cells with it, connecting the remainder in the local circuit with the bell. The arrangement was completely successful. The leakage was reduced within reasonable terms, and in place of the signals becoming weak shortly after the battery had been renewed, they remained loud and strong all the time. I was able also to economize in the maintenance of the battery by changing some of the relay cells with some of the main battery cells from time to time.

Mr. J. D. MORGAN (*in reply*): There seems to be a slight misconception underlying Professor Kapp's quotation from page 108 of the paper. The words are preceded by the statement "there seems to be no sufficient reason for the assumption that the energy, etc.," and this makes it clear that I do not consider a measure of the circuit conditions prior to sparking can be regarded as a measure of

the incendency of the spark. Professor Kapp's analysis of the conditions existing in the external circuit of a mining bell system, and his practical suggestion to modify those conditions and make them harmless by ballasting the line with condensers, give me confidence to feel that the paper was worth writing if only to elicit his valuable contribution to the discussion. His scheme is obviously sound and should be seriously considered by those interested in the safety of mines.

I cannot quite agree with Dr. Garrard that all sparks in contact with the atmosphere of a mine are dangerous, because experience proves that some sparks are quite harmless. Exposed sparks though normally innocuous should, however, always be avoided if possible, lest abnormal conditions should occur in which such sparks might be dangerous. Enclosed switches can provide a safe system, but having regard to the convenience of bare wires and the readiness with which they can be rendered safe, there seems to be scarcely any need for anything more elaborate unless the atmospheric conditions of the mine are specially dangerous. I do not know whether I correctly understand Dr. Garrard's statement that it has been found that with sufficient coal dust an explosion can be caused by sparks in an atmosphere containing only  $\frac{1}{2}$  per cent of gas. Presumably reference is made to an investigation by Professor Thornton. In a paper read before the British Association in 1913 Professor Thornton states that as little as  $\frac{1}{2}$  per cent of gas has effect in raising the probability of ignition of coal dust in air. I do not believe that a dust explosion can be initiated by any sparking likely to occur on a signal-bell system, even with a small percentage of gas present. The gas would have to be sufficient in amount to form with air an explosive mixture. In the presence of sufficient dust the resulting flame might set up a dust explosion. I have no data as to the maximum pressures obtainable in explosions of the gases found in mines, but no doubt such pressures are minimized by contact of the gases with large cooling surfaces. I quite agree with Dr. Garrard's statement as to the conditions which should be complied with in the construction of a case or cover for electrical mining apparatus, but I should like to add that the case might also be provided with a leak to prevent the attainment of high internal pressure without permitting the escape of flame.

Mr. Young states that it is easy to see that the energy appearing in the spark of an inductive circuit should be  $\frac{1}{2} L I^2$ . With this I am unable to agree, for the reasons set out in the paper. The expression implies that all the energy appears in the spark, and it does not take into account the losses in the circuit or the absorption at the sparking points. I do not know of any simple method of obtaining the electrical energy of a spark from a non-inductive circuit. The oscillogram has been used, but there is no consensus of opinion as to the reliability of the ordinary instrument for that purpose. Mr. Young is possibly right in stating that it would have been much better if experimenters had plotted curves showing how the energy of an igniting spark varies with the percentage of methane, but seeing that the energy was not definitely known the only safe procedure was adopted. I should not like at this stage to commit myself to a definite opinion as to whether a unidirectional spark is more effective in the production of an explosion than an oscillatory spark.

Mr. Morgan.

Mr. Morgan. Professor Thornton has shown that an alternating-current spark is less effective than that of an equivalent continuous current, but the frequencies dealt with were low. Sir Oliver Lodge has shown that an oscillatory spark exhibits more mechanical violence than a unidirectional one. It may be that the oscillatory spark for that reason is capable of setting up a turbulence effect which accelerates ignition, but definite data on this point are needed. When I state that the incendency of a spark depends upon its duration, I fear I have used slightly ambiguous language and I thank Mr. Young for referring to the point. It would be more accurate to state that incendency depends upon the duration of sparking. I have only definite experience of the condition in which ignition is obtained from a rapid succession of single sparks any one of which alone could not produce ignition. This result is probably due to some local action of a cumulative character, perhaps heating, which makes it possible for an otherwise ineffective spark to cause ignition. When ignition is to be produced by a given single discharge I should expect the chance of ignition to be increased by shortening the duration of discharge. There is not within my knowledge any definite information as to the minimum amount of energy required to produce ignition of a given gas mixture ; it varies with the percentage of the mixture and the character of the gas. Some figures have been published for a few gases, but

whether these figures are independent of the circuit Mr. Morgan's conditions is not stated.

Mr. Watson enters a very interesting domain when he examines the process of ignition as it spreads from a hypothetical hot core of burnt gas through an envelope of cold unburnt gas. This line of thought inevitably presents itself to the minds of those who attempt to work out problems associated with the ignition of gases. Closely connected with it is the idea that ignition depends upon the propagation of a wave of adiabatic compression through the gas. Difficulties are soon encountered in following out such ideas, because they assume only one agency, namely, heat, as the cause of ignition, and disregard the possible alternative of an electrical agency, except in so far as the latter is capable of producing heat. An enquiry along the lines of Dr. Railing's interesting suggestion would probably throw much light on ignition phenomena.

Mr. Walker is quite right in his statement that single-stroke bells can be made less dangerous than trembler bells, but I would point out that the danger from the bare signalling wires remains unaffected. Trembler bells are generally held to be more satisfactory for signalling purposes, but that I imagine is largely a matter of use. In any case trembler bells can be made quite safe and the outstanding danger is on the wires.

## ELECTRIC HEATING: ITS PRESENT POSITION AND FUTURE DEVELOPMENT.

By GEORGE WILKINSON, Member.

*(Paper first received 18 June, and received from 23 September, 1915; read before the SCOTTISH LOCAL SECTION 14 December, 1915.)*

There is probably no branch of electricity supply in a more flourishing condition to-day, or receiving greater attention from both electrical engineers and the public, than that of electric heating as applied to dwelling-houses and business premises.

Over two years ago the *Electrical Review*\* commenting on the enterprise of the "Point Fives" concluded its remarks as follows: "One might suggest that there is still scope for the 'point-five,' who feels inclined to become fractionally smaller still, to consider some scheme of heating at 'so much per room' during the winter months. Small heaters suitably placed and automatically controlled by a thermostat . . . adjusted so as to maintain a temperature of about 60° F., might meet the case; but, of course, it needs a really simple and reliable method of temperature control and a relatively low charge per unit, neither of which may materialize just yet."

Since the above comment appeared there has been little, if any, change either in tariffs or economy of usage; nevertheless the development of electric heating has made rapid progress, the rate of progress at the present day being greater than ever. This is largely due to improvements in the electric radiators themselves, these improvements having developed concurrently with a reduction in the prices of the apparatus. Radiators of modern design known under the generic term of "electric-fires" have proved themselves to be reliable and satisfactory, while the prices at which they can be obtained are more reasonable than formerly.

## INITIAL MISTAKES.

Until comparatively recent times electric heating was frequently brought into disrepute not only on account of high tariffs but also due to the fact that the radiator selected was too small for the apartment to be heated. Thus, while the electric fire did satisfactory duty in the chilly spring and autumn evenings, it entirely failed to heat the apartment in the winter. Other forms of heating had then to be resorted to, with the result that the electric heater fell into disrepute and was often permanently displaced.

## CORRECT RATING.

Electric heaters to be permanently satisfactory must be capable of quickly raising the atmosphere of the apartment to a comfortable temperature during the coldest day of winter and under the most unfavourable weather conditions. This entails a rating of not less than  $1\frac{1}{2}$  watts per cubic foot of room space. In apartments with abnormal window area, an exposed aspect, or subject to draughts and traffic, the rating should be at least 2 watts per cubic

foot. Assuming a rating of  $1\frac{1}{2}$  watts per cubic foot as being sufficient for the coldest day of winter, this rating is obviously too high and therefore wasteful for every other day of the year.

The crude regulation obtained by providing only one or two switches for an electric fire, whereby its power can be reduced to two-thirds and one-third of its full output, does not in any case furnish the required control.

First, because such switches are seldom used, or are not used at the right time and for the correct period; and

Secondly, because the external temperature and the weather conditions are constantly varying at irregular intervals, so that no simple combination of hand-operated switches can meet the case or prevent considerable waste of current.

It follows, therefore, that all apartments heated by electric fires of adequate power are at the present time (except in the few instances where thermostatic control is employed) costing substantially more for electric current than they should do, while such apartments are not so comfortable as they might be owing to the constant fluctuation of temperature ensuing on the unstable weather conditions.

Mr. W. A. Gillott has already demonstrated\* that an apartment is heated more economically by means of a high-power heater or heaters suitably controlled than by a heater or heaters of lower power in the aggregate continuously in operation.

## AUTOMATIC TEMPERATURE CONTROL.

The advantages of electric heating need not be commented on at length as they are already recognized. From the health standpoint, heating by electricity is ideal, there being no vitiation of the atmosphere. There are no fumes, dirt, or smoke, the quantity of oxygen is undiminished, and the apartment does not get "stuffy."

The few disadvantages may be set out as follows:—

- (a) With radiators of the correct power the apartment will, except on the coldest days, often become overheated; and an overheated room is almost as uncomfortable as one which is too cold, and it is also more unhealthy. This objection is not confined to electric heating but applies more seriously to all other forms of artificial heating, and it often accounts for the frequent colds and minor illnesses which few people escape during the cold season of the year.
- (b) This frequent overheating causes a great waste of the heating medium. Fortunately, in the case of electricity the way to prevent waste is obvious, pro-

\* *Electrical Review*, vol. 71, p. 687, 1912.\* *General E.E.E.*, vol. 53, p. 49, 1913.

vided inexpensive, simple, and reliable apparatus can be produced which will cut off or reduce the electric current when the desired temperature is reached, and which will re-establish the heating when a slight fall of temperature takes place.

Incidentally the author would call attention to the increased comfort which ensues on equable temperature. The benefits to both mind and body are by no means small, while the economy in cost of heating, its absolute cleanliness, and the prevention of waste of current by servants, bring electric heating, from a commercial standpoint, into line with other more crude and less healthy methods.

It is essential to complete success that automatic temperature regulation should not be obtained at the expense of cheerfulness, especially in living rooms where the ladies of the household insist on having a cheerful hearth to sit by.

#### SUPPLEMENTARY HEATING.

Another promising field open to electric heating with automatic temperature control is in the almost numberless cases where coal fires or hot-water radiators are in use. It is well known that both these methods of heating are subject to wide variations of temperature due to the vagaries

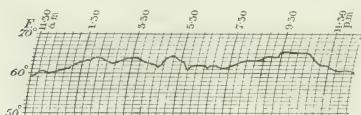


FIG. 1.

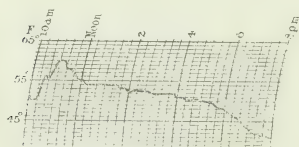


FIG. 2.

of combustion. It is not possible to co-ordinate the rate of combustion with the constantly varying weather conditions, consequently the apartments are frequently too hot for comfort and at other times dangerously cool. If a thermographic chart is taken, the temperature line will show frequent and erratic depressions representing cool or cold periods. The application of temperature-controlled electric radiators as an auxiliary method of heating will automatically remove these cool periods at little expense for current and with no trouble or attention, thus producing the ideal condition for comfort and health.

A typical temperature chart taken in a sitting-room with a south-west aspect and heated by a coal fire, is shown in Fig. 1.

This chart was obtained in March last on a day which was sunny and warm for the time of year. The room was

occupied by an elderly lady who is always attentive to the firing but was unaware that a temperature chart was being taken.

Fig. 2 is a temperature chart taken in an office heated by a gas radiator. It will be noticed that the temperature rose rapidly from 50° to 60° F. in the first hour, after which the gas was turned down owing to the uncomfortably dry and choky atmosphere, after which the temperature steadily declined to 50° F. at closing time. The gas radiator used is of a well-known modern type in which, as stated in the manufacturer's catalogue, "a white non-burnen flame of great heat is used which produces no carbon monoxide and consumes all the component parts of the gas. No flue is therefore necessary, and the whole of the heat is kept in the room."

It is well known that for long periods during the spring and autumn, and occasionally in the summer, there are days when the mornings and evenings are cold while the rest of the day is warm and comfortable. During these seasons coal fires or hot-water radiators are inconvenient. If they are used the apartment is too hot for the greater part of the day and waste of fuel takes place; moreover, the occupants have either to suffer discomfort from overheating in the daytime, or to endure a chilly atmosphere during the earlier hours of the day and in the evening. The only economical and effective way of dealing with the heating problem during these periods appears to be by means of thermostatically controlled electric heaters ready for duty at all times, for long or short periods, and requiring no attention.

These considerations led the author to give serious attention to the production of a suitable automatic temperature controller.

The only apparatus available at the time, so far as the author's knowledge goes, was the "Grundy" system. This, while effective for big installations, appears to be too bulky, expensive, and complicated for general adoption; also an additional difficulty is that a supplementary battery of low voltage is necessary.

It would make this paper too long to describe the many experiments made before success appeared to be even remotely assured. It is therefore proposed to describe first the apparatus used until the autumn of this year.

#### APPARATUS FOR AUTOMATIC TEMPERATURE CONTROL.

This controller, which is absolutely silent in its operations, has no mechanical moving parts, the only moving element being mercury.

The apparatus consists of two parts:

- (a) The thermostat, shown in Figs. 3 and 4.
- (b) The circuit breaker, shown in Figs. 5 and 6.

A diagram of connections is shown in Fig. 8.

**Thermostat.**—The thermostat is constructed with a steel tubular body terminating in a faucet at the top, surmounting which is a fine-bore glass tube enclosed by an inverted glass dome. The steel tubular body is charged with mercury which, due to expansion and contraction under the influence of heat variation, rises and falls in the fine-bore glass tube into which the mercury chamber vents. Within this glass tube a platinum wire is suspended which makes and breaks contact with the mercury as the latter rises or falls due to heat variation. It will be obvious that so far the thermo-

stat corresponds in principle with thermostats already extensively in use. It has been found, however, that such thermostats are capable of dealing with extremely small currents at low pressure only, thus a voltaic or other battery is a necessary adjunct to their use. For reliable and successful use it is desirable that such a thermostat should operate, without oxidation of the mercury or destructive sparking, on the higher pressures used by electricity-supply authorities.

This is achieved by surrounding the "make and break" contact by an inert gas. By referring to Figs. 3 and 4

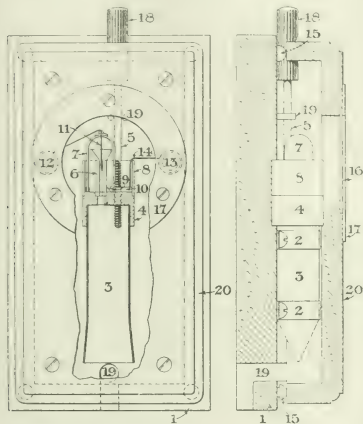


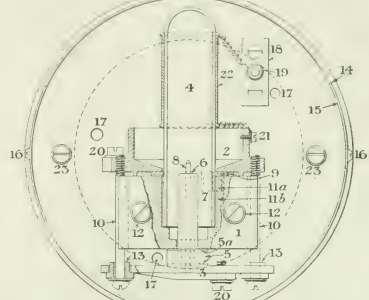
FIG. 3.

FIG. 4.

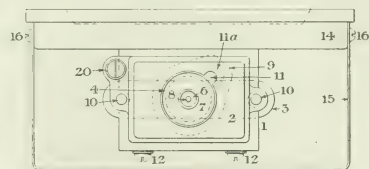
1. Base. 2. Metal tube. 3. Steel tube filled with mercury. 4. Cover carrying temperature-indicating screw. 5. Capillary tube. 6. Glass dome. 7. Which is hermetically sealed. 8. Mercury seal carried in the glass ring. 9. Slot in glass dome. 10. Winding of the thermostat. 11. Inert gas. 12. Inert gas. 13. Inert gas. 14. Inert gas. 15. Inert gas. 16. Inert gas. 17. Inert gas. 18. Inert gas. 19. Inert gas. 20. Inert gas.

it will be seen that this is accomplished by carrying the platinum wire through the top of a superimposed glass dome into which it is hermetically sealed. The rim of the glass dome is closed round the bottom by a mercury seal in the faucet, thus forming a permanently gas-tight chamber of sufficiently flexible dimensions to allow the mercury column to travel freely the whole length of the fine-bore tube. The glass dome is filled with a suitable inert gas, preferably hydrogen. It will be noted that the platinum contact is fixed, but the temperature at which the instrument operates can be controlled by screwing or unscrewing the adjusting screw protruding through the top of the

cover. Thus the thermostat can be readily set to any desired temperature. Due to the protection afforded by the inert gas, the thermostat is capable of breaking an alternating or continuous-current circuit conveying 30 watts or over at 250 volts without destructive sparking or discoloration at the point of "make and break." This is about five to six times its normal duty.



Elevation Part in Section.



Plan. (Winding, and Connections not Shown)

FIGS. 5 and 6.

1. Porcelain block. 2. Iron tray forming one pole of the circuit breaker. 3. Bar forming the other pole of the circuit breaker. 4. Glass tube closed at upper end and filled with inert gas. 5. Hollow porcelain insulator. 6. Rubber packing rings. 7. Annular spaces filled with mercury and forming the two poles of the circuit breaker. 8. Steel pin indicating the correct level of the mercury on charging. 9. Rubber packing-ring. 10. Fixing screws securing the mercury tray and the bottom bar to the porcelain block. 11. Mercury duct between the glass chamber 4 and the mercury tray 2. 11a. Snag cast on tray 2 in which is formed the mercury duct 11. 11b. Continuation of the mercury duct 11 in the porcelain block to the chamber 4. 12. Wood screws fixing the instrument to the base 14. 13. Insulator. 15. Pressed steel cover. 16. Fixing screws for the same. 17. Leading-in holes for the connecting wires. 18. Porcelain block carrying insulated terminal 19. 20. Main terminal screws. 22. Heating coil of fine high-resistance wires connected to terminals 19 and 21. 23. Screws for fixing circuit breaker to wall.

**Circuit breaker.**—This is formed by two bodies of mercury concentrically arranged and forming the two poles of the electric circuit. The point of "make and break" is on the top rim of the hollow porcelain insulator separating the two concentric mercury poles. The "make and break" takes place in an inert gas which is impounded by the superimposed glass tube carried in the earthenware fixing block. The outer pole of mercury also fulfils the

function of a permanent gas-tight seal to the tubular glass chamber. The arrangements of the parts will be quite clear from Figs. 5 and 6, in which it will be seen that the inner mercury pole makes contact with the bottom insulated metal bar to which one line wire is attached. The outer mercury pole makes electrical contact with the metal dish surmounting the earthenware fixing block, and to this metal dish the other line wire is attached. The "make and break" is effected between the two poles by the slow rise and fall of the concentric ring of mercury. Notwithstanding this slow rise and fall, however, both the "make" and "break" are instantaneous owing to the surface tension of the mercury, and the breaker can be depended upon to interrupt a current of 20 amperes at 250 volts without oxidization or discolorization. The breakers have successfully dealt with a current of 30 amperes at 200 volts (6 kilowatts), but the standard rating is fixed at 15 amperes.

It now remains to describe how the rise and fall of the mercury within the breaker are controlled by the thermostat. A small coil of enamelled high-resistance wire is wound upon the cylindrical glass chamber of the breaker as shown in the illustrations. This coil, which takes approximately 8 watts, is connected through the thermostat to one pole of the supply as shown in Fig. 8. When the mercury rises to a point corresponding with the temperature for which it is set, contact is made in the fine-bore tube with the platinum wire, and the circuit is thus completed through the high-resistance heating coil upon the circuit breaker. This coil quickly becomes warm and causes the inert gas within the glass cylinder to expand, thus expelling a portion of the outer concentric column of mercury through the connecting duct into the surrounding receiver until the connection with the centre pole is broken, thus opening the circuit and putting the radiator out of action.

After the radiator circuit has been broken, the thermostat, due to cooling, also breaks the heating-coil circuit. The heating coil on the circuit breaker now cools and the gas contracts, causing the mercury forming the outer pole to rise until it stands well above the centre mercury pole; gradually the surface tension of the mercury is overcome, when it rolls over the edge of the concentric insulator and forms a complete contact over the whole surface, thus putting the radiator to work once more. The radiator remains at work and heats the apartment until contact between the platinum wire and the mercury in the thermostat is re-established. The resulting small current again heats the coil on the circuit breaker, and in due course the supply to the radiator is again cut off. Thus the cycle is repeated from time to time as the temperature of the apartment reaches the maximum and minimum temperature variation allowed. If the outside temperature is equal to that for which the thermostat is set, it is obvious that the radiator circuit remains broken; when, however, the outside temperature falls a little below that for which the thermostat is set, the thermostat circuit is broken and the radiators are brought into action. Thus in the milder weather the electric heating is often confined to the early morning and late evening hours. It is essential for the thermostat only to be in the apartment which is electrically heated; the circuit breaker can be located elsewhere if desired.

#### BAROMETRIC EFFECT.

It is obvious that the mercury within the circuit breaker is always subject to change of level due to barometric effect. The line in Fig. 7 shows that this variation approximates to  $\frac{1}{4}$  inch between the extreme limits of the barometer,

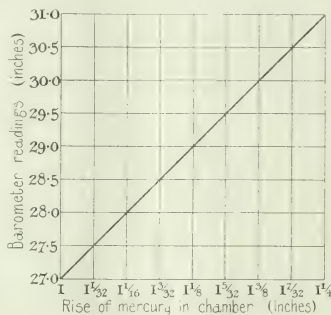


FIG. 7. Temperature Controller—Barometric Effect.

the level being highest when the barometer is high, and vice versa. The effect of this is slightly to vary the time of the operations of making and breaking circuit; but this is negligible in actual working.

#### CHARGING WITH INERT GAS.

An unusual feature in the equipment is that the instruments require charging with inert gas after they are fixed in position and charged with mercury. This may sound formidable, but is in practice a simple operation which can be carried out by any man of average intelligence.

The circuit breaker is fitted with a small rubber tube ( $\frac{1}{8}$  inch outside diameter) inserted in the passage 11 (see Fig. 6) with its inner end terminating in the upper part of the glass chamber 4, and the outer end of the tube terminates with a rubber cork with a hole through the centre.

A small glass-stoppered bottle containing the necessary liquid for the gas production is supplied together with the correct amount of zinc rod. After the circuit breaker is charged with the correct amount of mercury, as denoted by the centre pin 8, the gassing bottle is hung upon the breaker, the zinc rod is dropped into the liquid, and the rubber cork on the end of the rubber tube is inserted in the neck of the bottle in place of the glass stopper. Hydrogen is then evolved and passes through the rubber tube into the glass chamber 4 (Fig. 5), from which it first drives the mercury up into the receiver 2; then the air is expelled by bubbling through the mercury, and finally the chamber 4 becomes charged with hydrogen and the surplus follows the air through the mercury and escapes to the atmosphere. Ten minutes is ample time to secure the expulsion of all the air and a complete charge of hydrogen.

At the expiration of the charging time the rubber cork is withdrawn from the neck of the gassing bottle; this establishes equality of pressure between the gas in the glass chamber 4 and the atmosphere, whereupon mercury in the tray 2 flows back into the chamber 4 to its original level, expelling the surplus gas to the atmosphere through the rubber tube. The rubber tube is then gently withdrawn and the charge is complete and permanent.

The thermostat is first filled completely and slowly with mercury by means of a paper funnel through the tapped hole from which the adjusting screw 5 is withdrawn, the filling continuing until the mercury is seen to rise up and overflow the capillary tube 6, after which it is continued until the opening in the glass bell-jar 7 is completely submerged. The funnel is now withdrawn and the adjusting screw 5 inserted.

Meanwhile the liquid in the gassing bottle is continuing to evolve hydrogen; this gas is now passed into the small glass dome 7 by re-inserting the rubber cork in the gassing bottle, slipping the glass pipette provided on the other end of the rubber tube and inserting it beneath the mercury seal and through the hole 9 in the side of the glass dome 7. This expels the air from the dome through the mercury seal to the atmosphere, followed in due course by the surplus hydrogen, after which the pipette is withdrawn and the remainder of the gas evolved by the gassing bottle is wasted.

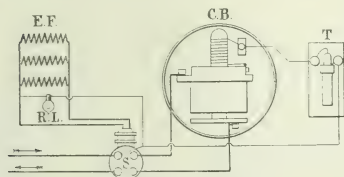


Fig. 8.—Diagram of Connections.

- C.B. Circuit breaker.
- T Four-terminal plug switch.
- R.L. Red-lamp filamentous radiator, not controlled.

The setting screw 18 is now withdrawn until the mercury in the capillary tube and the platinum wire are well apart. After the radiators have raised the apartment to the required temperature the setting screw 18 is screwed in until the mercury just touches the platinum wire, when the instrument is set.

Variation in temperature up or down can be readily obtained by screwing the setting screw further out or in.

In starting up, as a measure of safety, it is always desirable to effect the first break by the circuit breaker with the metal cover 15 in place, in case the gas-filling instructions not having been correctly carried out a mixture of air and hydrogen is left in the tube 4, in which case the spark on breaking may cause a slight explosion and possibly crack the glass. After the first break no such trouble can arise.

#### OTHER USES.

It is obvious that the thermostat can be put to other useful purposes. For instance, in the summer it can be

connected to a 30-watt fan at 200–250 volts, and set so that the fan automatically starts when the temperature of the room rises above, say, 65° F., and stops when it falls below, say, 62° F.; thus the fan requires no attention and cannot waste electric current. An electric fan so controlled has been in use in the author's office all last summer with excellent results.

Again the author is of opinion that switches for high-tension circuits can be made on the lines of the circuit breaker, which would present advantages both in cost, safety, size, and convenience over the well-known oil-break switches. In such cases the "make and break" would be controlled by raising and lowering the gas chamber in the mercury seal.

Such a high-tension switch is shown diagrammatically in Fig. 9.

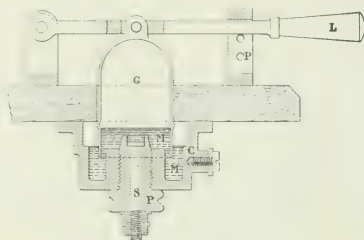


Fig. 9. Diagram of High-tension Switch.

- G Glass dome charged with inert gas.
- M Mercury seal also running pole of high-tension current.
- P Porcelain insulator.
- S Steel pin forming one terminal.
- C Metal contact forming one terminal.
- L Operating lever.
- P Le clamping pin holes.

There are also many cases where a reliable electric contact is required which is used at long and indefinite periods only—such, for instance, as fire-alarms and alarms for other purposes. In such cases the ordinary contacts are liable to fail owing to dirt, roughness, or oxidation. Mercury in hydrogen makes a reliable contact which can be depended upon for all time notwithstanding absence of attention and long periods of disuse.

#### THERMOSTATIC REGULATION OF GAS STOVES.

The author has experimentally applied thermostatic regulation to a gas stove of modern type for heating his study. The temperature chart, Fig. 10, shows a typical

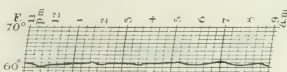


Fig. 10.

result taken throughout the night of the 26th March, 1915, when there were 2 degrees of frost and a light fall of snow outside. From the point of view of equable temperature the result is ideal, but in practice the effect was disappoint-

ing owing to the dismal intervals intervening between the heating-up periods. During these cooling intervals the jets were reduced to the smallest size consistent with safety; the clay fuel then lost its incandescence, producing a corresponding dullness and, notwithstanding a practically steady temperature, the cooling intervals felt comparatively chilly due to the loss of the radiant-heat rays.

If, however, a satisfactory gas-heating equipment can be evolved which will give at all times a uniform cheerfulness in the shape of a small amount of radiant heat and provide the bulk of the heating by "black heat," which alone would be thermostatically controlled, similar substantial economies will then be open to gas that are available in the case of electric heating.

In the example given, the stove consumed 30 cubic feet of gas per hour when on at full, and approximately 25 per cent of this amount when reduced by the thermostat.

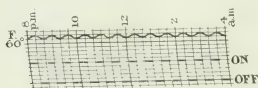


FIG. 11. - 6 February, 1915.

Fig. 11 shows a 6-hour temperature chart taken in an office, with a corresponding pressure chart showing the periods when the electric radiator was on and off. The size of the radiator was 2 kilowatts, equivalent to a rating of  $1\frac{1}{2}$  watts per cubic foot.

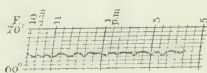


FIG. 12. - 12 January, 1914.

Fig. 12 shows a temperature chart taken in the same office with a 6-kw. radiator in use, which is equal to a rating of  $4\frac{1}{2}$  watts per cubic foot. The circuit breaker was carrying 100 per cent above its rated load and the circuit was broken and re-made approximately every 10 minutes. The periods during which the radiator was "on" were short, and the "off" intervals were long.

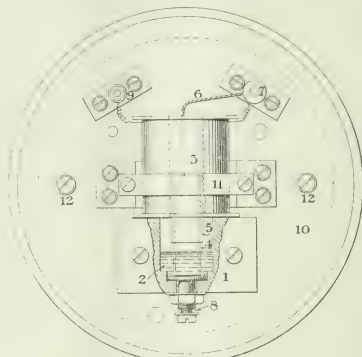
#### LATER TYPE OF CONTROLLER.

The controller already described has been unfavourably criticized due to the fact that both the thermostat and the circuit breaker require charging with inert gas after fixing. Again their field of application is limited due to the type of circuit breaker used; for instance it is obvious that it cannot be used on board ship or on a train.

Both these objections have been successfully met in the more recent types as follows:—

The thermostat is now made with a very small glass dome surmounting the capillary tube and having a gas space of less than one-sixth the capacity of the earlier pattern. The small amount of air impounded therein by the mercury seal is not expelled, but the oxygen it contains is allowed to combine with the mercury at the point of

"make and break" while the thermostat is at work. After working for a short time the mercury absorbs the small amount of oxygen in the impounded air and a film of mer-



Elevation.

FIG. 13.

1 Porcelain block, part in section. 2 Mercury bulb. 3 Shunt coil. 4 Steel armature forming part of the electric circuit. 5 Paper covering on upper part of armature. 6 Flexible conductor from armature to terminal 7 and 8. Terminals. 9 Shunt-wire terminal. 10 Wood base. 11 Clip securing shunt coil in position. 12 Fixing-screws.

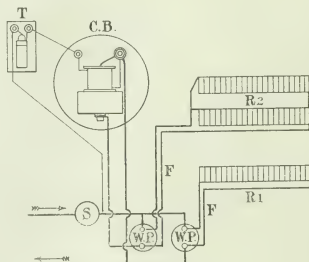


FIG. 14. —Diagram of Connections of Losles Automatic Temperature Controller.

T. Thermostat.  
C.B. Circuit breaker.  
R<sub>1</sub>. Small radiator, hot-bars or red lamp, controlled by switch S only.  
R<sub>2</sub>. Larger radiator, convectors or hot bars automatically controlled.  
W.P. Wall plugs.  
F. Flexible wires to heaters.  
S. Control switch.  
Note. Switches upon the radiators are not necessary.

curious oxide gradually forms in the upper part of the capillary tube, thereby making the temperature regulation less accurate. This oxide is then expelled and washed over into the mercury seal by screwing down the adjusting

screw, thus again providing clean pure mercury at the point of "make and break" and restoring the sensitivity of the instrument. After the wash-over the thermostat is again set to the required temperature point and the mercury then continues to "make and break" without deterioration.

The circuit breaker is of the magnetic class and has a light moving element of the simplest type. The construction will be readily understood by reference to Fig. 13, which shows the circuit breaker with the cover removed. The energy absorbed by the shunt coil when the heating circuit is broken is about equal to the loss in a modern electricity meter, viz. approximately 2 watts. The split iron tube performs the double function of armature and conductor; it falls by gravity into the mercury bath and rests upon the terminal at the bottom of the mercury bath, thus completing the heating circuit. The break is very quick owing to the light moving element, while the spark on breaking is most effectively blown out by the strong magnetic field set up by the shunt coil on the end of the armature.

This type of circuit breaker has operated continuously at from 15 to 20 breaks an hour on a circuit loaded to 3·25 kilowatts, and has aggregated over 10,000 interruptions with little or no wear on the end of the armature; thus it can be depended upon to operate for years without attention.

Fig. 14 shows an alternative diagram of connections which permits of the splitting up of a large radiator into two parts, one part (the smaller part) being continuously in use while the other part (the major portion) is put under the control of the temperature regulator.

Judging from observation made last winter, the author is led to believe that a considerable economy in current consumption for a given result can be obtained by the use of a small "uncontrolled" radiator in the hearth—for cheerful effect—together with a convector or convectors of greater power, thermostatically controlled, the latter forming the main source of heat. Rough comparisons between this method and the use of a thermostatically controlled all-radiant fire used in the same apartment point to a small saving in current in favour of the combined arrangement.

#### RADIANT VERSUS CONVECTED HEAT.

The problem here involved is common to all methods of heating and is by no means a settled question, viz. to what extent should the air of an apartment be heated, and to what extent should radiant heat be supplied. The question will be answered differently by different individuals, but probably some mean can be arrived at. There is reason to think that experiments on radiant electric heaters in conjunction with electric convection heaters would be the easiest way to arrive at some general basis for the correct proportion of heat in each form.

#### DISCUSSION.

Mr. R. WEAVING: The paper deals with electric heating from a new point of view. I have carried out a number of experiments which confirm Mr. Gillott's experience that a high loading of electric heating apparatus is economical, and with the aid of a thermostat still higher loadings may be used and further economy effected. Previous thermostats, while they might be left to regulate the temperature of the atmosphere, themselves required a great deal of attention. I had some experience in regulating the heating of a freezing machine by means of thermometers with platinum wires fused in, and though these thermometers had to break only 10 watts, the sparking was so bad that they were useless until a condenser was fitted across the break. The thermostat and circuit breaker described in the paper are very simple, and, speaking from experience, seem to be very reliable. I have found the thermostat to break with ease 30 watts at 200 volts. Manufactured in quantities the apparatus should be inexpensive. In fact a modern electric fire with thermostat should not cost much more than a fire alone would have done a few years ago. The principal feature in the thermostat described is that it dispenses with a battery. I think the author has missed an opportunity of giving some interesting figures with regard to cost. As the result of a number of tests I have found that for heating purposes electricity at  $\frac{1}{2}$ d. per unit is equal to gas at 2s. 3d. per 1,000 cubic feet. If the author had calculated costs with such fine temperature regulation the results would have been reliable and valuable. On page 210 the author shows for a coal fire a heating curve which is a testimonial to the careful stoker. The peaks and valleys on a curve with average firing are much more pronounced.

The statement on page 214 as to the absence of glow making a room appear chilly can be confirmed by almost anyone, and there is no doubt that the convector failed because it had not the appearance of a fire. I was always under the impression that this was an illusion, and I cannot understand why more economical results can be obtained with a combination of a glow-lamp radiator and a convector than by other means. Perhaps the author can enlighten me on this point. The concluding paragraph of the paper raises a point which has caused some discussion, but the presence of radiant heat for the warming of the person is essential, and a room to be comfortable must have the air warmed by convection. But why use a lamp radiator plus a convector, when an electric fire, giving both convected and radiant heat, pleases everyone? In this matter as in others the fittest survives, and the large proportion of electric fires now sold as compared with lamp radiators and convectors leaves no doubt in my mind which will be the survivor. A defect in the thermostat which could be easily remedied is that in its present form it cannot be immersed in water to regulate the temperature since the heating container is alive. Some modification of the design is also required to make the thermostat applicable to oven temperatures.

Mr. W. W. LACKIE: The paper is confined entirely to Mr. Lackie's heating of business premises and dwelling houses. The author first refers to initial mistakes and incorrect rating, and while I agree with a great deal of what he says, I think it has to be borne in mind that heating with coal fires has been wrongly carried out up to the present. It appears to me that in order to fill a cup with water a

Mr. Weaving.

Mr. Lackie. bucketful has been used. A moderate fire consumes 4 lb. of coal per hour, and if we take ordinary house coal as having a calorific value of 10,000 B.Th.U.'s per pound it will be seen that 40,000 B.Th.U.'s have been expended. This would mean that to heat a similar room electrically a radiator taking 12 kw. would be necessary, whereas a 1- or 2-kw. radiator would be found sufficient to provide an equal quantity of useful heat. This simply confirms that from 80 to 90 per cent of the heat of ordinary coal as used in a coal fire goes up the chimney. The principal recommendation in favour of the electric radiator is that it can be placed in the exact position where the heat is wanted. The author gives some figures showing the quantity of electrical energy necessary to heat a room, viz.  $1\frac{1}{2}$  to 2 watts per cubic foot. While this amount of energy may be necessary to heat a large area, there are many places where less would do. For instance, in a dining room of 3,600 cubic feet capacity I have found a 1-kw. radiator placed under the table to give as good results as a big coal fire. In November of last year the Glasgow Corporation rented premises for the administration of the Prince of Wales Relief Fund, and the Town Clerk stipulated that there were to be no charges for the administration of the Fund. The Electricity Department were called upon to supply the necessary heating for these premises. The principal apartment was 60 ft. x 36 ft. x 12 ft. high, i.e. had a total capacity of 25,000 cubic feet. By arranging the radiators alongside individual desks ample heating was found to be provided by the installation of radiators taking a total of 10 kw. The premises were occupied for practically a year and the consumption of energy was 17,000 units, which at  $\frac{3}{4}$ d. per unit cost  $\pounds 55$  or a return of  $\pounds 5$  10s. per kilowatt. At the top of page 214 the author refers to experiments with thermostatic regulation of a gas fire giving disappointing results owing to the dismal interval intervening between the heating-up periods. Will the same effect not be apparent on electric radiators? The author adds a note on the subject of radiant versus convected heat. I think it is generally admitted that radiators should be designed to give off a large percentage of radiant heat. A captain on a 4,000-ton tramp steamer had a 4-element 1,000-watt dull radiator fitted in his cabin and complained of feeling cold with an air temperature of 67° F. Two of the 250-watt elements were removed and replaced by one radiant element taking 230 watts. With an air temperature of 57° F. he then said he felt quite warm; that is to say, 730 watts gave him more satisfaction than 1,000 watts had done previously. The author might have added something about electric furnaces for re-heating, heat-treating, and annealing of metals. I confidently anticipate that in the immediate future we shall have a very large outlet for the use of electrical energy in connection with this class of work. The *Electrician* recently contained two papers\* on the subject which are well worth careful perusal. An electric furnace of  $\frac{1}{2}$ -ton capacity per hour takes 200 kw. continuously for 24 hours. Heating apparatus is being daily improved not only in regard to variety of design, but also as to efficiency and first cost, and the supply authorities are doing their part by offering special terms to consumers taking energy for heating purposes. There is still much to do, however, in educating the public as to the possibilities of heating and cooking by electricity.

\* *Electrician*, vol. 76, pp. 158 and 159, 1915.

The Glasgow Corporation is now attending to this important branch of the work by means of a showroom which was opened about three months ago. In the first 10 weeks our showroom sold 450 pieces of electrical apparatus representing 752 kw. These sales are not to be taken as indicating all the publicity work that has resulted from the showroom, as we have had repeated testimony from contractors and firms who deal in such appliances that increased custom has been traced to advice given by our showroom staff. An important example of electric heating and cooking is to be found in a Glasgow suburb called Dumbreck, where eight villas have been equipped electrically throughout. The size of these houses varies from 7,000 to 12,000 cubic feet, and each house has 10 to 12 kw. of heating appliances including water heating. The largest consumption for any one of the houses for the year ended May 1915 was 14,000 units, the bill being  $\pounds 40$ . In other cases the annual consumption was only half of this. Speaking broadly, however, the consumption of electrical energy in a house may be anything from 10 to 50 times what it would be if electricity were used only for lighting. These eight villas are all supplied from one main. The aggregate maximum demand taken on one of the recent very cold days in November was only 17 kw., which gives a diversity factor of 5 on the total of 80 kw. installed. This is practically the same diversity factor as we have in lighting. In Glasgow we have 10,000 domestic consumers, and 2,500 of these have electric heating appliances of some kind. Their total consumption is 500,000 units for lighting, and for other purposes 1,000,000 units. A large number of street lavatories in Glasgow have water heaters installed, taking from 3 to 10 kw. each. The annual bill for these varies from  $\pounds 7$  to  $\pounds 30$  per annum, depending on the size of lavatory, and I am glad to say we have had no complaint about the cost, nor have we had serious trouble with the apparatus. An application of electric heating which is easily commended is the heating of glue pots in joiners' workshops. I recently had to investigate a case of this kind where 13 kw. of apparatus was used entirely for the heating of glue pots. The annual bill was  $\pounds 63$  and after experience with gas heating the consumer was perfectly satisfied with his electric heaters. In Glasgow we have some 70 police signal-boxes scattered throughout the city, and in each of these there is an electric hot-plate for the convenience of the policemen on the beat. Mr. Goslin, electrical engineer to the Glasgow Corporation Tramways Department, has given me some very valuable information with regard to the electric heating of the Head Office of the Tramways Department. They have had electric heating installed for 10 years. At first a hot-water system was in use, but they found it unsuitable owing to the various hours of work in the different offices of the Department. Mr. Goslin, like others who have investigated this problem, has found that the question of electric heating is bound up with the question of ventilation. The author suggests that if a temperature of 60° F. be maintained it might meet the case, but this seems to ignore the question of ventilation. Where heating is adequate without the accompanying provision of ventilation, complaints are soon heard of dry throat and other forms of discomfort and irritation. Mr. Goslin's conclusions briefly are that with thermostatic control in one room the saving may be anything from 43 to 87 per cent. Without

thermostatic control he found a room became heated to 74° F., whereas with automatic control the temperature was kept between 59° F. and 60° F. Mr. Goslin has carried out a very comprehensive experiment in a test room where he had 36 thermometers placed throughout the room at different heights. He found, however, that there was as much as 10 degrees difference of temperature between the readings of a thermometer near the ceiling and of one near the floor-level; also that there was a difference of 5 degrees between the temperature near a window and that of an adjacent wall. This all points to the fact that the thermostat must be very carefully placed in a room. He also established the very practical fact that one watt-hour raises 100 cubic feet of air 1 degree F. Mr. Goslin recommends large low-temperature heaters and automatic air regulators.

Mr. R. ROBERTSON: This paper could not come at a more opportune moment, considering the present high price of fuel delivered to household bunkers, the difficulty of obtaining satisfactory domestic labour, and the present call for national and individual economy. The importance of the problem of domestic heating may be gauged from the remark of Mr. Sparks in his recent Inaugural Address\* that domestic requirements are about 10 times that of lighting. This proportion is in my opinion by no means exaggerated, as from personal observation I would estimate the domestic heating alone in a residential district to require not less than 8 times the lighting supply. This is, therefore, what we as supply authorities have to endeavour by every reasonable means to secure, and I would thank the author for what he has done to add to our knowledge and the means at our disposal for this work. Being a firm believer in the ultimate greater development of electric heating in private houses, I have followed with great interest the development of electric heating apparatus, and it is satisfactory to note the great strides that have been made in recent years in the efficiency and first cost of such apparatus. The industry undoubtedly received a severe set-back not very many years ago owing to the installation of electric radiators much too small for the work they were required to do. It was quite common for householders to install 4-bulb luminous radiators of the same size in superficial area as a coal fire and to expect the same results in temperature rise and heat maintenance. The author's minimum figure of 1½ watts per cubic foot of air to be heated is, I should think, very nearly correct. From my own observation and experiment I obtained a fairly satisfactory result, keeping an average room temperature of 59° F. in the month of November—generally a very trying month—with a rating of 13½ watts per square foot. Taking an average room height of 10 ft. this gives 136 watts per cubic foot, i.e. a very similar figure to the author's when a correction is made for temperature. My results were entirely obtained with radiant-heat radiators and ordinary control. In tabulating my data I was much struck with the divergent results obtained in different rooms due to the position of doors, windows, fireplaces, etc., some rooms requiring as much as 25 per cent more than others per cubic foot, and I cordially agree with the author's finding, that the best results are to be obtained by the installation of a small luminous radiator for cheerful effect and a large

controlled radiator for temperature rise and maintenance. Mr. Robertson  
For the thermostat and circuit breaker outlined by the author to be a success, one would have to be installed in each room of a house, as I take it that owing to temperature difficulties the thermostat could not very well form an integral part of the radiator itself. This is undoubtedly an objection from a capital-outlay point of view, and one of the great advantages of electric fires in a house is the facility of removal from one room to another. Would the author kindly give in his reply the present cost of the thermostat and circuit breaker as one unit, and say whether the latest type of magnetic circuit breaker is suitable for operating on alternating current of low frequency. Further, in his experiments was he able to determine the amount or percentage of the saving in current due to the installation of the thermostatic circuit breaker as against ordinary control under similar conditions. If a saving of anything approaching 75 per cent can be obtained, as in the case of gas, the case is clearly made out for thermostatic control and any extra capital cost would be more than justified. From the general tenor of the paper I think the author has in mind a proportion of 25 per cent non-controlled radiant heat and 75 per cent convected heat in controlled form, and this may modify the saving to some extent. Turning to the apparatus itself, any work other than simple fixing required in a consumer's premises is an undoubted drawback. I take it that the improved apparatus outlined on page 214 also requires gas charging, although the author states that this is only one-sixth of that in the original type. Can the charging be done in the laboratory before issue?

Mr. E. HUGHES: On page 209, a conclusion attributed to Mr. Gillott is stated in such a way that one would interpret it to mean that in order to maintain a room at a constant temperature a high-power heater suitably controlled is more economical than a heater of the correct capacity continuously in operation. Not being satisfied with this interpretation, I looked up Mr. Gillott's paper.\* The results of two experiments are there given in the form of curves, and from these Mr. Gillott concludes that "it is cheaper to heat a room by using a large heater as the room is heated quickly, and a low consumption is then all that is required to overcome the losses due to leakage through doors, walls," etc. This conclusion seems to me to be fundamentally incorrect, since the heat lost from any room depends upon the amount by which the temperature of the room exceeds that of the outside atmosphere, other factors remaining unaltered. If a room is heated up quickly, then for a given maximum temperature, its average temperature must be higher and more heat has to be supplied than when the room is heated slowly. This consideration led me to examine Mr. Gillott's curves more carefully, and it was found—amongst other things—that the current and the energy curves are not consistent with each other. For example, when the current is decreased, the power in one place increases; while in other places the power varies though the current remains constant. In fact, the many discrepancies and the different conditions under which the experiments were performed render Mr. Gillott's conclusions quite unreliable. On page 215, Mr. Wilkinson returns to the question of the relative economy of all-controlled and partly-controlled heaters. Why should there be any difference in the

\* Page 1.

\* *J. Inst. E.E.E.*, vol. 53, p. 42, 1915.

Mr. Hughes energy consumption of two heaters of different capacities which maintain the temperature of a room constant within 1 degree C.? Surely the amount of heat carried from the room is the same in the two cases, the only difference being that one is on for a longer period and off for a shorter period than the other. In connection with the circuit breaker shown in Fig. 13, the author claims that "the spark on breaking is most effectively blown out by the strong magnetic field set up by the shunt coil on the end of the armature." Now it is well known that a conductor carrying a current in a direction perpendicular to a magnetic field has a force acting upon it tending to urge it from that field. This is the principle of the moving-coil instrument and of the electric motor. But in the author's device, the arc—which can be looked upon as a conductor—is carrying a current in the direction of the magnetic field. Why is it, then, that the arc is blown out? It seems to me that the satisfactory operation of this circuit breaker is due to the quickness of the break rather than to any magnetic action. In this connection, I should like to know why condensers are not used on this class of apparatus, since by that means the arcing can be almost eliminated by adjusting the capacity of the condenser to the proper value. Is this due to the cost or to unreliability? Next, let us turn to Fig. 11. This curve indicates that the heater has maintained the temperature between 61° F. and 62° F. for a period of 8 hours by being switched on and off at regular periods of 20 minutes. This could only be the case, however, if the external conditions remained constant, but this is very unlikely when one considers that the test lasted from 8 p.m. until 4 a.m. Finally, let us look at Fig. 12. Here the current was on for, say, 2 minutes and off for about 8 minutes. We would consequently expect a curve similar in shape to the teeth of a saw—rising fairly quickly and falling slowly with peaks at intervals of about 10 minutes. In the actual curve, however, the shortest time between two consecutive peaks is about 20 minutes, whilst in several cases the interval is as much as 40 minutes. If this departure from the expected curve is due to external effects, why is Fig. 11 immune from them?

Mr. W. R. COOPER (*communicated*): From the point of simplicity and cheapness it is an advantage to make the thermostat also play the part of the main circuit breaker. There are many devices that may be so used provided both the current and the voltage are small. Where, however, this is not the case, difficulties arise. If reliance is placed upon the expansion of simple metals, the movement at the break is very small and cannot be magnified beyond, say, 20 times without introducing uncertainty in definiteness in the cut-off temperature. On the other hand, such devices as bimetallic strips and Bourdon tubes, which give greater movement, do not provide sufficient pressure on the contact to carry any but the smallest currents. For these reasons I have resorted to the expansion of liquids, which is so much greater than that of solids, and have modified the relay of the well-known Tubular Fire Alarm of Associated Fire Alarms, Ltd., so as to act as a thermostat. The arrangement is seen in Fig. A. As shown, there is a small water reservoir A, which terminates in a diaphragm B. When, through the expansion of the water, the diaphragm rises to a certain point depending on the setting of the screw C, the lever D is forced up and breaks

the circuit at the contact E. When the circuit is closed, Mr. Cooper, the contacts are kept together by a spiral spring F, which may be quite strong, as the force exerted by the expanding water is considerable. Sparking is reduced to a minimum by connecting a condenser of about 0.25 mfd. across the contacts. The arrangement is quite small, being only 5½ in. long, even when the condenser is included within the case, and is cheap. The sensitiveness may be made

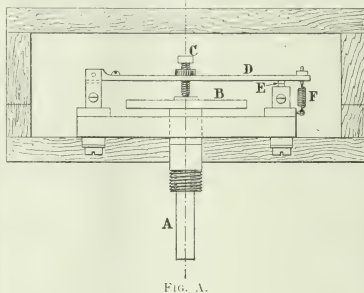


FIG. A.

anything that is desired by suitably proportioning the water reservoir. I have used the device experimentally for the direct control of 1 kw. at 220 volts, but I am not yet able to say to what extent larger powers might be handled in this way. In temperature control the handling of 1 kw. should prove sufficient in many cases, as it is only necessary to control a portion of the power used.

Mr. S. F. WALKER (*communicated*): I have followed the development of electric heating very closely, and the first remark I wish to make on this paper is that electric heating appears to be following the same course as other electrical inventions. I pioneered a good many electrical inventions, and the course they took was always the same. At first one could hardly persuade any possible user to look at them, but by good luck one sometimes found a case where, in spite of its higher price and less reliability, the apparatus was so convenient and so useful that it was installed. With the experience obtained there, one was able to reduce the cost and to increase the reliability. And so it went on, until finally the reliability was at least as great as the apparatus that was displaced, provided that it was properly looked after, and the cost, taking everything into account, was less. I agree with the author in his remarks as to the early forms of heating apparatus. The same remarks were made about every new electrical appliance that has been placed upon the market. The makers of the new apparatus very rarely appreciated the difficulties that would be met with. When the problem was approached from the electrical side, the experience of previous electrical apparatus led to faulty construction in the new form. For instance, when electric light was first introduced, men who were quite familiar with telephone and telegraph work could not understand why larger conductors were required for carrying the lighting currents. The question of

mechanical strength in all electrical apparatus also, and particularly in new forms of apparatus, is very often neglected. The higher price of electric heating appliances, as the author remarks, combined with its unreliability, were naturally very heavy drawbacks. I am also strongly in agreement with him as to the sanguine estimates that were made about electrical appliances for warming living rooms, churches, etc. The men who were introducing electrical heating appliances for the purpose had apparently no knowledge of heating rooms and buildings generally. I should say that the author's estimate of  $1\frac{1}{2}$  watts and 2 watts per cubic foot of air should be sufficient for heating ordinary living rooms; but in matters of this kind it is always wise to have a large margin in hand. Living rooms and halls for meetings, etc., vary in their conditions very much. The existence of a long north wall, possibly with several windows in it, adds to the quantity of heat required very largely. The quality of the building itself also has a very important bearing upon the question. A great deal can also be done—if the owners of the houses will allow—to lessen the quantity of heat required, by thermally insulating the walls and the windows. In very cold districts doubling the windows will have a very beneficial effect. Dry, still air is the best thermal insulator known. That is not exactly obtained by doubling the windows, but the presence of a layer of air between the two windows offers a fairly considerable thermal resistance. I am in full agreement with the author also as to the waste of the heating agent that arises from the want of automatic regulation. My house is heated entirely by gas (I am not within the range of the electrical supply), and I find that this is far more economical and much more convenient than heating by coal fires. In spring and autumn, as the author points out, great economies are obtainable if means of regulation exist. In a large hospital in the Midlands in which the wards are heated by low-pressure steam radiators, it is claimed that considerable economies are obtained during the bright hours of some days in spring and autumn by turning off the supply of steam to those wards on which the sun is shining. To effect this what is practically a steam switchboard is fixed in the central heating station, and the attendant switches off any block, or groups of blocks, at will. The same thing could, of course, be accomplished electrically; and a later development of the same idea is the control of the temperature in individual hospital wards by the aid of thermostats. There is no doubt whatever that some form of thermostat is advisable, but in my opinion it is doubtful whether the private householder can be persuaded to use it. It should certainly be of service for controlling the heating of public institutions when electricity is sufficiently cheap to capture that field. I should like to ask the author, however, if he has not found any trouble due to the mercury refusing to leave the platinum wire, which has always proved to be the difficulty with similar apparatus. I confess, also, that I have some doubts about the use of hydrogen gas. I presume that the author has employed hydrogen gas because it is easily and cheaply made, while nitrogen would be expensive, but I think that the latter gas should be used.

Mr. W. A. GILLOTT (*communicated*) : I quite agree with the author's remarks that the initial mistakes on electric heating were due to consumers using radiators too small

for the rooms in which the radiators were installed. This was undoubtedly due to the fact that electric heating of a few years ago was retarded on account of the unfavourable tariffs then in operation. However, now that this obstacle has been removed, we are in a better position to push electric heating. As the author states, in the paper which I read before the Institution last year\* I clearly demonstrated that the best results were obtained by using a large heater in place of a small one. With regard to automatic temperature control, this is an extremely interesting point, and we are indebted to the author for describing the results of some of his tests. I think, however, that the tests could have been made much more interesting by including the cost of heating in addition to the temperature curves, and if he could enlighten me as to the cost of electric heating compared with gas heating under the tests which he carried out, it would be of considerable interest. Also he does not state where the thermometer or thermostat was situated during the test, neither does he state whether there was one or several. It is, of course, well known that the temperature in a room varies in the different positions; therefore, in order to obtain a true and satisfactory reading, several thermometers or thermostats should be utilized, or the thermostat set to the required mean temperature of the room. I presume, of course, that this has been already done. Personally, I have yet to be convinced that a thermostat is the right thing to use in a private house. I quite agree that a thermostat would be very useful in places such as public buildings, theatres, etc., but where a private house is concerned the question is of a quite different nature. In the first place, thermostats must either be fitted in every room where electric heating is proposed to be installed, or the thermostat must be of such a construction to enable it to be portable, which is not to be recommended. The author does not give us the cost of these thermostats; one is therefore unable to judge whether the saving obtained by their use warrants their cost. So far my experience with thermostats has been very unfortunate. I have obtained as good, if not better results by hand operation than by a thermostat, probably mainly on account of the thermostat being unreliable. I quite agree it is essential that where a thermostat is used it should be designed to operate on a certain section of the apparatus which will not interfere with the cheerfulness of the radiator. It is quite evident that if the thermostat disconnects the radiator when persons are sitting in front of the latter, electric heating will lose its popularity, as far as outward appearance is concerned, on account of the thermostat operating at unsuitable times. The author advocates on page 215 the use of an uncontrolled radiator in the hearth. Personally, I question whether the use of a radiator permanently running in the hearth and convectors thermostatically controlled would make any real saving as against a good radiator in the hearth, hand-operated. From my experience with North Country people, they prefer a radiator that "scorches their shins" to the black heat given off by a convector.

Mr. C. G. NOBBS (*communicated*) : The title of the paper led me to expect a dissertation upon the vagaries of the human subject in his present and future demands for the electric heating of rooms, but it appears to consist mainly

Mr. Gillett.

Mr. Nobbs.

\* *Journal I.E.E.*, vol. 53, p. 42, 1915.

of a specification of the author's experimental apparatus for automatic temperature control, and to contain little information as to the economy or other advantages (if any) to the consumer. Undoubtedly the author's apparatus is very ingenious and interesting, but I fear it is too complicated and delicate a mechanism for safe transit or handling by the ordinary electrician. In my opinion there is a comparatively small field for automatic temperature control as applied to electric heating of rooms in dwelling houses. The majority of consumers purchase electric radiators or fires principally for their high radiant-heat efficiency; and compare one make of fire with another by the feel, cleanliness and convenience being secondary considerations. A comparatively low-temperature fire or convector finds but little favour. Now a reasonably efficient, or shall I say satisfactory electric fire from the consumer's point of view should be of not less than 2 kw. capacity and of intense radiant heat, *i.e.* with the heating wire or elements running at a temperature of 1,500° F. (cherry red colour), combined with a reflector to focus the heat rays on the person. For satisfactory and quick heating, not less than 2 watts per cubic foot of space should be allowed for radiant heating. It is admitted that radiant heat is the most wasteful of energy for air warming; probably 40 per cent of the heat is lost to the room by the heat rays striking walls and windows. In calculating heating surface ratings for low-pressure hot-water heating, when used as auxiliary heating, it is usual to allow about 50 per cent heating value for the fire under most average conditions for dwelling houses in Great Britain. In spite of the extravagant radiant method of heating, householders will insist upon a red-hot fire effect that they can turn up or down at will. Now my point is that for dwelling rooms of ordinary size we are compelled to supply more than the necessary B.Th.U. (in the form of radiant heat) required to maintain equable thermometer temperatures; consequently, additional or auxiliary heating by convection with or without automatic control is unnecessary. A high-power radiant heater will warm a room quickly enough to satisfy the consumer. Therefore auxiliary heating automatically controlled will increase the consumer's bill for current by reason of its maintaining an equable temperature in the room when it may not be required; it is easily forgotten, and if not switched out by hand or a time switch will continue in operation throughout the night. Most householders are quite capable of turning a radiator switch off and on, or will instruct the maid, or take it out of the hands of the maid according to the fluctuations of the bill for current. An economical radio-convector that will give intense radiant heat at full power or half power, and a low temperature convector effect at quarter power, is easily obtained by using a series-parallel 3-heat switch. Such an arrangement is provided in electric heaters known as the "Falco" electric fires. In my office such a fire is installed having a heating capacity equivalent to 2 watts per cubic foot; recent observations taken on five consecutive days gave the following approximate results. There is no auxiliary heating in or near the office; and the outside temperature varied between 27° F. and 35° F. for the five days. The inside temperature was taken by a thermometer hung on the window architrave (the coldest part of the room), and registered an average temperature of 39° F. at 9 a.m. for those days. The fire was switched on to full heat each

morning at 9 a.m. and raised the temperature as registered by the window thermometer to 55° F. within 60 minutes. The switch was then turned to half-power radiant heat until 12.30. The temperature rose 2 or 3 degrees in this time, and the switch was then turned to quarter power (convection heat); during lunch time and at 2 p.m. the thermometer temperature was found to have been maintained. During the afternoon until 5.30 p.m. quarter heat was found to be sufficient with but few exceptions, when it was necessary to switch on to full or half heat for a few minutes to raise the temperature which had fallen due to frequent visits of the staff necessitating opening the door, thus letting in chilly draughts. For private office heating this radio-convector is ideal. Auto-control would be of no benefit; when one arrives in the morning quick heating of the radiant kind is necessary, and at times for warming oneself after a walk round the works. For large offices there may be a comparatively small field for electric heating with auto-control, owing to the very low running costs of central heating systems by water or steam. It would be extremely interesting to have results of tests upon the energy consumption of electric convectors by hand and auto control, and also that of a low-temperature convector, say of the electric hot-water type, compared with a high-temperature radiant fire, both operated automatically. I made tests some 5 or 6 years ago by hand-switch control of two such heaters, the conditions being as nearly alike as possible. The electric hot-water convector showed a saving of approximately 25 to 35 per cent of electricity for similar mean thermometer temperatures, and of course from a heating engineer's point of view gave by far the best results, warming being most equable throughout the room, whereas the radiant heater gave a patchy heating effect. Undoubtedly there is a field for automatic control of electric heating of special rooms, wine cellars, etc., but by far the greatest demand would be in connection with manufacturing processes and industrial applications, water heating, oil-fuel heating, etc., where electricity can be applied commercially. A simple, reliable, and not too expensive tank form of thermometer of the adjustable bi-metal type, and an automatic switch suitable for breaking currents up to 30 amperes at 250 volts (c.c.) 2- and 3-wire, would find a ready sale, and would be suitable for water, other liquids, and metals. In my experience, battery-operated mercury thermometers and auto switches have not proved satisfactory. In conclusion, the heating engineer of to-day has much to learn of the methods of heating by radiation or convection; and whatever the heating medium may be, and no matter how exact his coefficients, he will always have to face the varying requirements of the "human factor."

Mr. G. WILKINSON (*in reply*): I am pleased that Mr. Weaving has been able to bear independent testimony with regard to the instruments. Although he has not had them long they have had a strenuous time while in his possession. Mr. Weaving and others have asked why there are no £ s. d. statements in the paper. The reason is that while one is busy with a task entailing research, the question of the actual amount of saving in cost of operation is apt to be left in abeyance. The absence of the figures asked for, therefore, must simply be set down to lack of time on my part to get them out. I should like some independent individual to experiment with the apparatus and

obtain this information, which would be of great value. Mr. Weaving has said that the thermostat as shown is not suitable for the regulation of temperatures in water or in ovens. This can easily be got over, however, by the elimination of the vulcanite and the substitution of insulated metal and glass only. These materials will easily stand a temperature in excess of the maximum required in water or cooking ovens.

I agree with Mr. Lackie in his plea for having the radiator exactly in the position where the heat is wanted. I made a radiator of circular shape for a workmen's club. The elements were enclosed in a perforated copper case and it stood in the centre of the room. I also use a similar radiator, thermostatically controlled, for heating the meter-testing apartment. In both cases the results have been excellent, a comfortable effect with a maximum economy being obtained.

The figures given by Mr. Lackie with regard to the sales from his showroom in 10 weeks show conclusively the soundness of the business policy which led to the showroom being established. Mr. Goslin's figures, quoted by Mr. Lackie, showing 43 to 78 per cent saving due to automatic temperature control are convincing evidence of the value of such control. The dismal effect due to loss of radiant heat in the temperature-regulated gas-stove is not present in the case of the electric radiators, as one or two heating elements in the radiator are left uncontrolled and also the red lamp is always in operation, thus the cheerful effect is always maintained.

Mr. Robertson makes a definite request with regard to the cost of my apparatus, and while one hesitates to give prices of any apparatus in an Institution paper, I may say that the cost of the thermostat and circuit breaker will be approximately 52s. 6d., with say 2s. 6d. for the resistance required for use with the higher pressures. The apparatus is equally fitted for use on alternating or continuous-current circuits, but the initial sparking in the thermostat is more pronounced with continuous current until the oxygen beneath the glass dome is absorbed. On the other hand, the stable period is more quickly reached than with alternating current when the resulting mercurous oxide can be washed over into the sealing space and the thermostat permanently set to its operating temperature.

With regard to the saving effected by the use of the apparatus, as before explained I cannot give figures but I refer inquirers to Mr. Goslin's figures quoted by Mr. Lackie. The amount of radiant heat desirable, compared with convected heat, is problematical and possibly varies due to local conditions. My investigations, however, have demonstrated the immediate need for electric convectors which are not too hot on their external surfaces to blister the paint on the skirting-boards, or to burn the children; it is difficult to understand why makers have not already produced such convectors for the market.

Mr. Lackie refers to the important matter of ventilation, and in this connection I have to say that in all my experiments the top sash of the window has always been open. The upper part of the room is the correct place for an air vent and not the fireplace, which simply scours out the fresh air from the lower part of the room instead of the heated foul air which naturally rises to the top part of the room from which it should be removed. The difficulty raised about thermostatic regulation of radiators which have

to be frequently moved from room to room does not really exist, as thermostatic regulation is not called for where radiators are used for only a few minutes at a time. Present practice tends more and more to the permanent installation of radiators in the apartments to be heated and to their continuous use daily in the cold weather. It is in these cases where automatic control is so valuable and economical.

Replying to Mr. Robertson's last question, it is clearly explained in the paper that the new type of thermostat does not require gassing; it produces its own inert gas.

Mr. Hughes states that the heat lost from a room depends upon the amount by which the temperature of the room exceeds that of the outside atmosphere, "other factors remaining unaltered." The unfortunate fact is that on most days the "other factors" do not remain unaltered but on the contrary are continually varying almost from moment to moment. These variables consist in the irregular intervals of sunshine, constant change of position of the sun, veering and velocity of the wind, change in humidity of the atmosphere, change in external temperature, and irregular cooling due to frequent entrance and traffic through the room. No radiator can be set to meet these variables, and no combination of switches can produce the necessary changes, even if it were possible to give them constant attention.

The question is raised as to the magnetic effect in blowing out the arc in the circuit breaker. With the criticism offered I am in agreement, as the following experiments subsequently made appear to afford confirmatory evidence:

(a) The standard pattern circuit breaker was operated on single-phase alternating current at 200 volts, the current being gradually increased to 75 amperes (15 kw), and in every case the break was successfully effected.

(b) The armature was elongated about 4 in. by a non-magnetic metal and was finished at the breaking point with an iron ferrule of the same shape and section as the armature. The earthenware block containing the breaking chamber was lowered a corresponding amount, thus removing the break from the electric field. A shunt coil absorbing 3 watts was substituted, in place of the standard 2-watt coil, to compensate for the increased weight of the moving element. Under these conditions the circuit was successfully broken repeatedly with the same loads and with little, if any, increase in the arcing.

The success of the breaker on these extremely heavy loads therefore appears to be due to the great rapidity of the break and not to the magnetic effect. I am inviting Mr. Hughes to repeat the experiments on the same circuit breaker with continuous current and I hope to get some oscillographic records of the results.

The question of introducing condensers to reduce the arcing on breaking circuit has been raised. Practical daily working under commercial conditions demonstrates that condensers are unnecessary, and their introduction would increase the cost of the apparatus and add needless complication.

Mr. Cooper submits a diagram of a combined thermostat and circuit breaker depending for its operation upon the expansion of a liquid acting upon a diaphragm which in turn lifts a lever and breaks contact on the end

Mr. Wilkinson.

thereof. There is no quick-break action, and reliance is placed on condensers for reducing the arc set up on breaking the radiator circuit. I have used a similar device but furnished with a simple form of quick "make and break," thus enabling a circuit of 3 kw. at 200 volts to be dealt with. It was found that the action of the device was far too sluggish, the heating and cooling of the liquid with the small range of temperature being very slow. If the liquid chamber was made larger so as to increase the sensitiveness of the device, then the diaphragm was distorted or burst by the abnormal expansion during the warmer days when the radiators were not required. Mr. Cooper appears to have had little experience with the device and on small loads only.

Mr. Walker inquires if trouble has been found in the thermostats due to the mercury refusing to leave the platinum wire. This was a great difficulty in the early thermostats with very fine-bore tubes, but it does not affect the working of the Losles thermostat, probably because the bore in the capillary tube is many times greater in sectional area than in the earlier types of thermostats. This is also one feature which enables the thermostat successfully to control a circuit in the summer time operating a 30-watt ventilating fan. If Mr. Walker will read the concluding portion of the paper again he will find that the inert gas in the thermostat is chiefly nitrogen formed from the impounded atmosphere deprived of its oxygen.

## THE ELECTRICAL RESISTANCE OF SOME HEAT-TREATED COPPER-ZINC-NICKEL ALLOYS. (PART I.)

By F. C. THOMPSON, M.Met., B.Sc.

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Despite the extreme importance of the copper-zinc-nickel alloys usually known as German silvers in the construction of electrical resistances, definite data concerning the influence of composition and heat treatment are almost wanting. A few odd determinations, in almost all cases without any chemical analysis, or details of heat treatment, are alone available. Resistances made from these alloys, and the closely allied "platinoid," are also apt to exhibit curious and unexpected changes, and often undergo spontaneous fracture, the reasons for which are often obscure. It appeared advisable, therefore, to conduct a systematic investigation on the electrical resistances of the whole range of compositions employed in practice, and at the same time to determine for the hard-drawn wire of each alloy the exact effect of annealing.

The alloys were made from electrolytic copper and zinc and Mond nickel of the highest degree of commercial purity. Copper-zinc and copper-nickel basis alloys of 50 per cent each element were first made, which were remelted with the necessary additions of new metals. No scrap was used at all. The melting was carried out in graphite crucibles in a coke-fired crucible furnace, in quantities of about 1 kilogram, and the alloy was cast into dry sand moulds. From each cast wires of 0.03 in. diameter were drawn and left in the hard, unannealed state. In every respect the production was typical of the best commercial practice.

In view of the extensive use of small quantities of metallic manganese as a deoxidant during the melting of these alloys, the effect of which on the resistance is unknown, each composition was made in duplicate. One cast was untreated whilst the other received an addition of 0.25 per cent of Thermit manganese a few minutes before casting. In two cases the influence of manganese was further investigated and additions of 1.5 per cent were

made. In the final ingot, however, no manganese could be detected analytically, the whole having passed into the slag.

The general scheme of the compositions chosen was to make alloys with a fixed content of copper (60 per cent) and then to vary the nickel percentage from 7 to 28

TABLE I.

Analyses of Nickel Silvers.

No.	Copper %	Nickel %	Zinc %	Manganese %	Manganese added %
250	60.6	7.62	31.7	Nil	Nil
257	60.2	7.80	31.8	"	0.25
258	61.8	10.4	21.7	"	Nil
259	61.2	15.5	23.2	"	0.25
260	61.6	22.4	15.85	"	Nil
261	61.6	19.8	18.5	"	0.25
262	55.7	17.4	26.7	"	Nil
263	54.3	15.75	29.7	"	0.25
265	54.2	19.3	27.0	"	1.5
269	61.2	28.6	9.8	"	Nil
267	60.4	27.9	11.4	"	0.25
268	60.0	20.7	15.15	"	1.5

per cent in steps of 7 per cent. To determine the effect of changing the copper-zinc ratio an extra set of casts was included with 15 per cent nickel, but with only 55 per cent of copper. The exact analyses are recorded in Table 1.

The annealings were conducted *in vacuo* in a platinum

resistance furnace, the temperatures being measured by a platinum-platino-rhodium thermo-couple. Each set of 12 wires was treated simultaneously. The heating occupied about 25 minutes, and the specimens were maintained at the maximum temperature for a further period of 5 minutes.

In view of the uncertainties arising from varying extents of oxidation during melting, involving alterations of com-

position, solution of oxides, etc., it was deemed unnecessary to determine the specific resistances with a very high degree of accuracy, since it would be virtually impossible to reproduce exactly the condition of the material. The determinations were carried out with a calibrated Post-

office resistance box, and after obtaining the position of balance as nearly as possible, the final value of the resistance was obtained by noting the deflections of the galvanometer on each side of the null point. A length of wire of 35 cm. was used, and the actual resistance was of the order of 30 ohms. The determinations were all made in duplicate at a temperature of 15°C.-17°C., the values being in excellent agreement. The results are

TABLE 2.  
*Specific Resistances of German Silver (Microhms per Centimetre Cube).*

N.	Heat Treated.	Annealing Temperatures, C.															
		245°	245°	250°	255°	260°	265°	270°	275°	280°	285°	290°	295°	300°	305°	310°	315°
256	22°2	21.6	22.0	21.1	20.7	19.3	18.8	18.2	17.9	18.3	18.4	18.6	19.0	19.5	19.5	19.2	
257	18.3	18.2	18.2	18.0	18.1	17.7	16.6	16.5	16.7	16.7	16.7	16.9	16.6	16.8	16.6	16.6	17.2
258	30.2	30.5	30.0	30.4	31.5	31.5	31.8	30.0	30.0	30.5	30.0	30.1	30.5	30.8	30.3	30.4	29.8
259	27.5	27.2	27.7	27.8	29.0	29.1	29.0	28.2	28.1	28.1	27.9	27.2	27.7	27.9	27.8	27.7	28.0
260	32.6	32.8	32.3	32.5	33.8	34.2	34.5	32.6	32.5	33.5	33.9	33.0	33.5	33.9	33.0	33.5	34.0
261	29.5	29.5	29.3	30.1	30.9	31.7	31.0	32.0	29.6	31.8	32.2	31.6	32.0	32.4	—	31.5	31.5
262	27.5	27.7	27.0	28.0	28.6	28.4	28.0	27.5	27.4	26.8	27.5	27.0	27.3	27.7	27.1	27.5	27.6
263	27.7	27.5	27.7	28.4	29.5	29.5	29.5	28.3	28.0	28.1	27.5	28.3	28.1	28.6	28.0	28.0	28.3
265	30.4	29.5	30.5	30.7	32.5	32.6	33.2	32.1	31.0	31.5	31.1	30.8	31.0	31.5	31.4	30.9	31.8
266	41.5	41.6	41.0	42.0	42.2	41.7	41.5	40.0	40.9	41.0	40.0	41.0	40.9	40.9	41.1	41.1	41.3
267	38.5	38.0	38.4	38.5	39.0	39.0	38.0	39.0	38.3	38.5	38.8	38.7	38.6	39.0	38.8	38.7	39.1
268	38.5	38.1	38.0	38.0	39.0	39.5	39.5	39.1	39.6	39.5	39.5	40.0	39.4	39.2	39.8	39.8	39.8

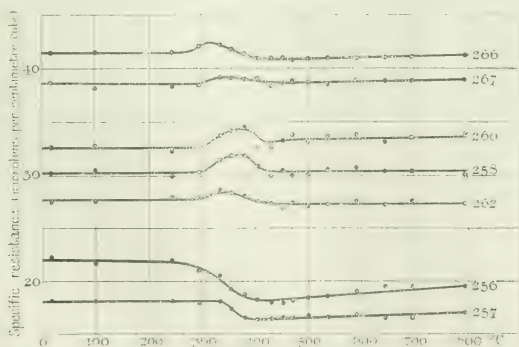


FIG. 1.

position, solution of oxides, etc., it was deemed unnecessary to determine the specific resistances with a very high degree of accuracy, since it would be virtually impossible to reproduce exactly the condition of the material. The determinations were carried out with a calibrated Post-

probably accurate to less than 0.5 per cent, which is amply sufficient for practical purposes. The results are recorded in Table 2, and several typical curves showing the relationship of the specific resistance to the temperature of annealing are plotted in Fig. 1.

The wires annealed at 100° C. are, however, exceptional. In order to determine to what extent prolonged exposures to comparatively low temperatures were likely to induce changes, a set of wires was maintained at a temperature of 100° C. in a steam oven for 40 hours. The change induced is in all cases inappreciable.

#### DISCUSSION OF RESULTS.

Perhaps the most surprising feature among the several points of interest revealed by the curves and figures is the distinct peak shown by all the alloys, with the exception of the two of lowest nickel content, in the neighbourhood of 300°C.-400°C. The temperature of annealing at which this maximum value of the specific resistance is found is independent of the nickel percentage, being essentially the same for the whole series. A similar change in the direction of the curve, indicating the relationship of the resistance of a similar alloy to temperature, has been discovered by Le Chatelier.\* The conditions under which the latter's work was done, however, were essentially different from those here described; unfortunately also no analysis of the alloy was given. It was distinctly stated, moreover, that the change proceeded with extreme slowness, whence the ease with which the corresponding change was obtained in the present cases is the more interesting. The importance of this change in connection with the construction of electrical resistances of German silver is obvious. A hard-drawn wire made into a resistance, and then heated by the passage of a current or otherwise to a temperature of 300°C., may show, on cooling, an alteration of resistance amounting to over 8 per cent. In addition, this critical range is, as the author has been able to satisfy himself by determination of the Brinell hardness, and by torsion and alternating-stress tests, one of very marked mechanical brittleness, which will readily explain the deterioration of German-silver resistances in the course of time, especially when subject to vibration. It would thus appear eminently advisable to utilize for the construction of electrical resistances only wires of German silver which have received a full annealing, in which, therefore, the change has been caused to complete itself beforehand. In these circumstances, both the electrical and mechanical stabilities will be markedly increased, and the irritating uncertainties arising from the use of such wire reduced.

Concerning the nature of the change, nothing need be said here, beyond the fact that it is not coincident with the true annealing temperature at which the extra hardness due to the wire drawing is removed, which is often at least 200 degrees C. higher. Up to the present, no microscopical change has been detected accompanying the electrical re-arrangement.

A point of considerable practical interest brought out by the work is the remarkably small change in specific resistance which results from the annealing of the hard-drawn wires. In the case of a pure metal and of most alloys, cold-working introduces a marked increase in the resistance, which is removed on reheating to the annealing temperature. The two alloys of lowest nickel content show the more or less typical curve, but in the other cases

the specific resistance is practically the same in both the hard drawn and the fully annealed conditions.

At first sight the alloys to which 0.25 per cent manganese has been added appear to possess a distinctly greater conductivity than the corresponding untreated samples. The chemical analyses are not quite identical, however, and when the values of the resistances are plotted against the nickel content, the alloys with manganese and without it lie equally on the straight line (Fig. 2). Similarly the change in the copper-zinc ratio in the cases of alloys 262, 263, and 265 has been without appreciable influence on the results. The curve indicates well the increase of resistance as the nickel content is increased, an increase of 1 per cent in the nickel producing an increase of 1.05 microhms per centimetre cube in the specific resistance. The interesting fact is thus brought to light that in the case of such pure alloys the specific resistance of the German silver is purely a function of the nickel content, neither change in heat treatment nor in chemical composition apart from the nickel producing any appreciable effect.

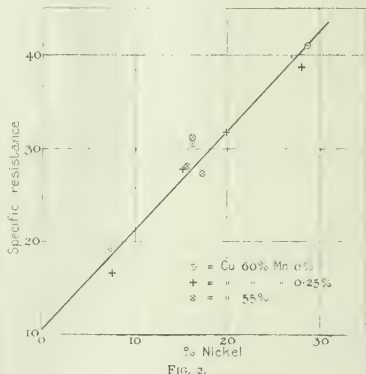


FIG. 2.

The present investigation has been carried out on materials of the highest commercial degree of purity, since the impurities usually found in ordinary samples, which are almost entirely in solid solution, produce a considerable increase of resistance. This is perhaps especially true of iron. When, therefore, the manufacture of such material of definite electrical properties is aimed at, the use of pure metals is essential.

The electrical work involved in the present paper was carried out in the Electrical Engineering Laboratories of the University of Sheffield, and the author takes this opportunity of expressing to Mr. E. H. Crapper, B.Eng., and to the whole staff, his grateful thanks for the help supplied. To Mr. G. B. Brook, who made the alloys, and to Mr. L. Aitchison, M.Met., who kindly analysed them, the author's thanks are also due.

\* LE CHATELIER "Contribution à l'étude des alliages." Paris, 1921, p. 415.

## DISCUSSION ON

## "THE DESIGN OF HIGH-PRESSURE DISTRIBUTION SYSTEMS."

DISCUSSION BEFORE THE INSTITUTION, 16 DECEMBER, 1915.

Mr. P. V. HUNTER: The preparation of this paper has to my knowledge required a very large amount of work by the author. I may instance Figs. 6, 7, and 13, which can only be arrived at by indirect methods involving laborious calculation. Then if we refer to the various diagrams in Fig. 9, it will be seen that the author has left nothing to chance in his consideration of the various types of system, and for each one of them he has thought it necessary to calculate the cost of the system not only with an average loading but with different loadings and different spacings; in short, no effort has been spared to consider sufficiently variable conditions to ensure that the deductions which the author makes from his calculations are to be relied on. The author's conclusions are in effect a justification of complicated distribution systems such as that of the North-East Coast, shown in Fig. 8. I believe the author's real reason for writing the paper was a desire to see whether the development which has been there carried out in a certain manner is justified on theoretical grounds and also, as he states on page 133, to give figures for the comparative values. The paper therefore, although theoretical in its treatment of the subjects, has an intense practical basis. I have always taken it for granted that interconnected systems are necessarily from their nature economical, although I have always felt that to prove it completely would be a complicated problem. My interest in the paper is therefore excited, not so much by the author's main conclusions, as by the subjects he has dealt with incidentally to the treatment of the problem. I refer particularly to the effect of copper losses on the load factor. I feel sure it was not generally realized that the copper losses could have such a widely different effect on the load factor of a transmission system. This is illustrated in Fig. 4, and it will be noted that the load factor of the copper losses for a system load-factor of 50 per cent may be anything between 25 and 50 per cent, which is to me quite remarkable. Another point which also surprised me was the shape of the curve in Fig. 5, which shows the most economical section of main for different carrying-capacities. I was surprised to find the most economical current density so low, but the explanation of this is apparently simple. The author has assumed a good load factor, and naturally on such a load factor the losses if the cable is run at a high current density would be considerable. It is advisable therefore to spend a little more capital in order to save the losses. The matter is also affected materially by the cost per unit of the losses. Some engineers will be inclined to disagree with the author's figure of  $\frac{1}{4}$  d. per unit for the lost energy, but in view of the way in which the losses alter the load factor there is a great deal to be said for the author's figure. In fact, on consideration, I am able to agree with it, although offhand I should not have to put the figure anything like as high as  $\frac{1}{4}$  d. per unit.

\* Paper by Mr. J. R. Beardsee page 125.

Mr. G. W. PARTRIDGE: I am very glad to see that the author refers to the early work of Dr. Ferranti when the pioneer extra-high-pressure transmission scheme from Deptford was first started. As I have been associated with this particular scheme from the very beginning, for a period of over 27 years, I am naturally very interested in all high-pressure distribution schemes. I am rather disappointed that the author has not gone more fully into pressures above 20,000 volts for underground cables. Under certain conditions, more especially as the use of electricity becomes more general and universal than it is to-day, pressures considerably above 20,000 volts will, I believe, be used, and in my opinion they appear to be quite feasible. I am at the present time considering systems of underground mains to operate at pressures up to 60,000 volts. From a transmission point of view I imagine there would be less difficulty in running such a system on a lower frequency such as 25 cycles, assuming that it is a large system. With the lower frequency there would be less trouble from inductance and capacity current; there would be less trouble in the rises in pressure due to switching, etc.; and of course large rotary converters and any railway supply would be more satisfactory at the lower frequency. At the same time, from the general point of utility I quite agree that 50 cycles is advantageous. At the lower frequency I think there is a great future for single-core lead-covered cables, more especially at these extra high pressures which I think will some day be used. The author has raised a great many points in connection with switchgear, and as this subject has had my careful consideration for many years, I think it may be of interest if I enlarge on it somewhat. During that period I think I have seen every possible kind of accident which can occur on switchgear. It is most important that the switchgear should always be kept proportional to the capacity of the generating station. The author emphasizes this point, and I heartily endorse what he says. I have so often seen systems laid out in the first instance for a comparatively small station capacity, and afterwards, when the capacity of the station has risen to 10 or perhaps 20 times the former amount, the old oil switches and even old-type fuses are still connected directly across the busbars of the station. The result is that sooner or later an old type of oil switch has to open a short-circuit with the total output of the generating plant behind it, the switch is destroyed, and possibly the whole station is shut down. Engineers should pay particular attention to this matter. I frequently see examples of this when visiting stations in this country. To give some idea of the size in which oil switches are now made, I am at present installing at our generating station oil switches each capable of dealing with over 200,000 kw. The generation of gases beneath the surface of the oil is one of the chief causes of the failure of oil switches. In my opinion the most essential feature of an oil switch should be first a quick break; and I would

Mr.  
Partridge

recommend as many breaks as possible, in order to dissipate the energy instead of concentrating it at one point under the oil. The second essential feature is a good head of oil above the break. It is much better to have a good head of oil and a comparatively short break, say about 6 in., than a long break and a small head of oil. I do not for one moment advocate a large amount of oil in the oil tank, but I do advocate this big head of oil. And lastly, as the author once more points out, it is most essential that the oil switch should be made as strong-as possible so that it can withstand the explosions which often take place. The pressure of gas set up in oil switches is in some cases enormous. I have known of one instance in which the contacts of the oil switch were blown together again after they had opened the circuit, owing to the gas acting on the plunger which passed through the gland—the plunger being made of wood had rather a large surface for the pressure to act on. This difficulty was overcome by reducing the size of the plunger; in other words, substituting a steel rod for the wooden rod. A most important matter to be borne in mind in connection with oil switches, in fact with all high-tension apparatus, is the necessity of covering up all bare parts in order to protect them against the discharging gases which come from the oil switches. I always make it a practice to cover up all conducting metal in the neighbourhood of an oil switch. When I was in America about two years ago, at one of the large power stations the chief engineer, knowing that I was interested in switchgear, arranged to destroy if possible two large oil switches. He connected generating plant rated at 36,000 k.v.a. to the switches, and we watched the results from behind iron shields. In the first experiment the switch opened the short-circuit; at the same time the gases coming out of the tank actually short-circuited all the terminals on the top of the switch and the latter was destroyed. Afterwards we saw the switches exploded after they had been tested in various ways. Another point that should be borne in mind is the protection of the busbars. In my opinion this is a very important matter. The author raises the difficulty of mice and rats getting on these bars and causing earths and short-circuits. I think it is much better to insulate the bars throughout their whole length, and if possible to build them into the brickwork at intervals, of course insulating them there with suitable porcelain insulators. It is a great mistake to have bare busbars only supported by porcelain insulators, as during external short-circuits these busbars have been known to fly apart and short-circuit the system, in some cases causing a general shut-down of the whole supply. The same remark would apply to the cleaning of high-pressure apparatus. In my opinion the apparatus should be designed so that it needs to be cleaned as little as possible. I have designed some new switchgear at our generating station—which I think is one of the dirtiest stations in the world—in which all the cables, and also the busbars, are single-core lead-covered; we have no cleaning because there is nothing to clean except the outside of the lead. The author has referred to a most important precaution, namely, the interlocking of the isolating switch and the main oil switch. I think this is a very necessary precaution. In my particular case the key which locks the isolating switch is under the control switch of the main oil switch, so that it is quite

Mr.  
Partridge

impossible for a man to get the key of the isolator without opening the main oil switch. The author refers on page 128 to reactances, and in his paper he does not consider them to be essential. I am inclined to agree with him, unless the system is working at a high pressure with a large amount of power behind it, in which case, apart from the reactances used in the generating station, which I think are essential, it would be advisable to use combined reactance switches. These switches have four contacts, the first pair of contacts putting in the reactance and the other two opening the circuit itself. Such switches are very necessary when large transformers or long lengths of mains are taken out or put into circuit, as they prevent rises in pressure and failure of plant in a great many cases. The magnetic switch referred to by the author on page 128 raises a very interesting problem. I have in our present station such a switch designed on the lines which the author suggests, but up to the present I have not had the courage or the time actually to test it. The author says "Attempts have been made to use the magnetic forces of the current for this purpose, since such an arrangement has the advantage that the more severe the short-circuit the greater is the speed of the break." In my experience it is very bad practice to open the circuit too quickly. In some cases I have known the switches endeavour to open the circuit on the top of the phase, in which case the switch has been blown to pieces; and in other cases the switches have opened when the first rush of current on the short-circuit took place, with very disastrous results. I think it is better to have a time lag in the opening of all switches; but when they do start to open they must open as quickly as possible. Before this unfortunate war I had an opportunity of visiting a great many of the Continental generating stations, and also the large generating stations in America. The switchgear in America is much better and stronger than anything I saw on the Continent. I considered the German switchgear especially to be much too light, and not capable of dealing with heavy short-circuits. I hope, however, that in the future we shall see no more German plant or switchgear in this country, or as a matter of fact, any more Germans.

Mr. B. WELBOURN: I am glad the author has brought the question of wayleaves forward again, and I am also glad that the increasing necessity for dealing with this urgent question was mentioned by our President in the Address\* he recently delivered. It is gratifying to know that the campaign is going forward and is receiving attention more and more. To illustrate the importance of the subject, I have heard to-day of two cases where, owing to farmers holding up wayleaves, £600 in one case and £300 in the other had to be spent to carry the overhead lines by longer routes. The paper is somewhat difficult for me to discuss because it confirms a view which I have held for upwards of 10 years, ever since Mr. Bernard Price did his classical work on the protection of mains, etc., namely, that the ring-main or inter-connected system is the correct one under most conditions of high-pressure supply. It makes the best use of the copper or other conductor; it gives the greatest possible flexibility; it affords the best way of maintaining pressure; and at the same time it gives a duplicate supply to every sub-station whether on a consumer's premises or otherwise. As the basis of nearly

Mr.  
Welbourn

\* Page 1.

all these curves, the author tells us on page 129 that he has allowed for the replacement of underground cables in 22½ years, and of overhead mains in 17½ years, but at the same time he mentions that it is a very conservative basis to work on. The subject is worth a little more consideration, because this year it has gone out to the Local Government Board, as the opinion of this Institution in connection with municipal loans, that the life of cables should be considered to be 30 years, and their decision has recently been announced in the *Journal*,\* that it should be taken as 25 years. If this average period is correct for low- and high-pressure cables, it follows that the life of high-pressure cables which are not tapped for services and are not, therefore, so vulnerable should be longer. In regard to overhead mains, it seems to me the author has considerably underestimated their life in taking only 17½ years. I have always considered the life of an overhead line to be the life of the pole, and I think there is a great deal of evidence from Post Office and National Telephone Company sources showing that the life of a properly-creosoted pole is not less than 35 years if it is not moved. I remember quite well at the time of the Post Office-National Telephone Arbitration much data was collected in regard to the life of poles, and I believe the Post Office gave it in evidence that the average life of their poles, including poles that were moved, was 22 years. I would therefore suggest that there is sufficient evidence from home experience alone to justify the author in reconsidering that figure of 17½ years. Then in regard to Table 4, I think it may be inferred from the paper that the author has considered the generating pressure in all cases to be 6,000 volts. If so, of course no step-up transformers would be required when transmitting at that pressure; but in all the distribution pressures that he considers, step-down transformers at the consumers' end are a common feature. At 11,000 volts and 20,000 volts, however, step-up transformers are necessary. I should like to ask the author whether he has included (which I think he should do) in the cost of the transmission main the cost of step-up transformers, and whether he has also made allowance for the running charges on them. There are other points in regard to the design of the high-pressure system which the author has not touched on and which I have not time to discuss to-night. I should like, however, to ask him what he considers to be the maximum number of kilowatts per cable which it is now safe to transmit. Of course the Board of Trade figure of 1,000 kw. per cable is altogether obsolete, and there is one scheme in this country where the distribution mains have been designed on the basis of its being safe to transmit 15,000 k.v.a. per cable at 33,000 volts.

Mr. W. B. WOODHOUSE: I entirely agree with Mr. Hunter's remarks in opening the discussion. There is so much information and so much work behind all these tables and curves that when one starts to try to follow the author in detail it takes quite a lot of time. This is a very valuable paper, and I do not think anyone is likely to dispute its main conclusion, that an interconnected system is the most economical. There are just one or two points on which I think the author might perhaps modify his basis. The first one is his definition of a well-designed distribution system. I think a further factor comes in in every prac-

tical case, and that is that an essential characteristic of the system is its suitability for development and extension on commercial lines. No system can be laid down commercially as complete; it is necessarily piecemeal, since it is impossible to say with the ordinary power-distribution system where the load will come from. It is therefore important that any particular system should take into account time and growth, so that as capital is spent it is used in such a way that a reasonable minimum return can be obtained on it during the period of development; this is particularly so in the case of electricity supply, because the annual turnover of the business represents such a small proportion of the capital. I think that is borne out rather well by the author's diagram of the North-East Coast system. It shows approximately 100 sub-stations out of a total of 350 depending on a single feeder. Those single feeders of course may be split-conductor mains or duplicate overhead mains, but, as the system develops, a large proportion of the load must be carried on what is in effect a single main. It is commercially necessary, and it is quite obviously a sound thing to do. I think anyone who knows anything about the North-East Coast system will agree that it is a splendid example of sound engineering, and one sees that as the system is extended these individual single mains will form part of the network. The author's diagram (a) on page 136 is a case in point. Suppose the necessity arises for another sub-station beyond the area already supplied, how is one going to deal with it? We cannot afford to lay down another square of mains. The economical method is to feed the sub-station with a single main and build it into the system as the latter develops. In considering the general lay-out of a network one must consider the case of the supply being given from more than one source. I think if one takes that into account the logical basis of the network becomes a honeycomb instead of a chess-board. Working out the relative amounts of copper, I think there is economy if one develops it on the basis of a hexagon rather than a square. The next point to which I wish to refer is the effect of growth on the economical voltage. Naturally one lays down the system to deal with the demands of, say, at the outside, 10 years ahead. I think in most cases in this country we have not been able to look as far as 10 years ahead, and so one develops a distribution at a particular voltage suitable for early needs. The natural development in a great many cases will be to adopt, in addition to the existing network, a further network at a higher pressure, and so ultimately between the source of power and the consumer we shall have our highest pressure network with very large meshes, an intermediate distribution of something like 10,000 volts, and the local isolated distribution at some lower voltage. That is the ultimate scheme, but the natural order of things is to install the highest pressure last. With regard to the economical loading of cables it seems to me that the criterion is not what the energy costs delivered at the sub-station, but rather what it costs after it has been transformed. That I think would be a fairer basis, it would take into account the transformer losses, which would rather militate against the smaller sub-stations and altogether would make the system more favourable to sub-stations at greater distances apart and of a larger output.

Mr. Woodhouse.

Mr. Brazil.

Mr. H. BRAZIL: I am generally in agreement with the author and other speakers, in advocating the use of the interconnected system, but I should like to discuss a modification of that system, which for some undertakings is a great advantage, particularly when one is considering continuity of supply and maintenance of pressure. The paper deals with the subject from the point of view of a power company supplying over an extensive area and with a large number of sub-stations, but to make the matter complete, I think it is advisable also to consider a company supplying in a very densely populated city, where the loads within a given area are very heavy. The author mentions 2,000 kw. as the maximum size of the sub-station with which he is dealing, but those I have in my mind would be of 3,500 to 4,000 kw. Owing to their size, the number of sub-stations in the scheme I am considering would necessarily be small, also the length of cable required to connect two cables to each sub-station and to interconnect the sub-stations would not be great. The system which I am advocating, and which for want of a better name I would call the interconnected interleaved system, has been in use for many years with success. Each sub-station has two cables direct from the generating station, one being denoted by an odd number and the other by an even number. All the odd cables are connected together in a ring, and the same thing is done with the even cables. The generating station is divided into two parts, which are readily connected together, one with odd machines and the other with even machines, and the sub-stations are treated in like manner. We then have two complete systems, the odd and the even, which are quite independent of one another. In addition, batteries which are capable of discharging very heavily for a short time, are installed in each sub-station. Normally, the two systems are kept coupled together, thus enabling the generators to be economically loaded, but as soon as the load exceeds a certain figure, say half the peak load, the two systems are divided and remain so until the load is again reduced below the figure mentioned above. With the exercise of a little care, economical running can be maintained whether the systems are coupled or divided. Assume that a fault occurs on one system necessitating the shutting down of that system; the load is immediately taken up on the batteries, and the faulty system being dead and entirely disconnected from the other, testing is much simplified. As soon as the fault is found, it is either remedied, or the faulty cable or machine cut out. The system is run up again and paralleled with the other system, and then if necessary the plant is again divided. I have known cases where a fault has occurred on the peak of the load and has been dealt with in the manner mentioned above, the consumers being hardly aware that anything has happened. I feel very strongly that we cannot emphasize too much the importance of maintenance of pressure and continuity of supply, and I therefore think that the particulars I have given of the working of this system may be of interest.

Mr. Wedmore.

Mr. E. B. WEDMORE: I think the moral of this paper is that we ought to err on the high side in selecting the distribution voltage and in choosing the cross-section of mains, and that we should be prepared to spend considerable sums of money in protective apparatus and switchgear to enable us to obtain the very substantial saving which

Mr. Wedmore.

the author shows to be possible. Many figures in this paper which are only small percentages may have, however, considerable effect on the balance sheet. The last column in Table 3 is of the very greatest financial importance. I wish the author could have extended his work to consider the proper price one ought to pay for plant of all kinds—transformers, generators, rotary converters, etc. There is no doubt that the problem whether one should spend, say, an extra £100 on any machine in order to reduce the losses is very seldom considered. A particular standard machine cannot possibly be the best machine for the different classes of service found in different parts of the country. On hydro-electric plant the conditions are different from those dealt with. At first it might be thought that the water costs nothing and that the losses are of small importance, but in a few years one may find that the water supply is limited, that there are customers who cannot be supplied, and that every unit lost represents a loss, not of a fraction of a farthing, but of the sum which it would fetch in the market. That entirely alters the complexion of the curves given in this paper, which of course are worked out for an entirely different system of generation and distribution. The problem of oil-switch design is becoming of increasing importance, as the author points out in the paper. It is quite clear that if we tie the network solidly together to obtain the great economy that is possible by so doing, we must use oil switches which can be relied upon, with a good factor of safety, to deal with the very large amount of power they may have to deal with on a short-circuit. Too many conclusions on oil-switch design have been drawn in the past on altogether inadequate data. It has not been realized how difficult it is to arrive at a conclusion on the function and relative importance of any one feature in the design of an oil switch. I have seen an oil switch tested at a point which should have been near its limit of rupturing capacity. The oil switch opened perfectly quietly in five consecutive tests, but on the sixth test it threw oil. The validity of the tests was challenged and another six tests were made, and in five out of those six the switch behaved very badly. It is necessary to make a very large number of tests, even under one given condition, to be sure that a valid conclusion is being reached. The question of what occurs in an oil switch when breaking circuit is of first importance. The feature of high pressure introduced by the inertia of the oil is one which has been known for some years. Examination of tanks which have been bulged by the effect of opening heavy short-circuits has alone given very clear indication of this action. The engineer is tempted to meet an irresistible force by setting up an immovable body, even if it were only to discover what the result would be; but the real engineering solution is to set up a body which is infinitely easily moved, thereby completely circumventing the irresistible force. I think there is no doubt that the light oil tanks which have been used so extensively in the past have performed a useful function from the point of view of dealing with the stresses due to inertia. One has to realize that if the tank gives and bulges only a little, this force, which might otherwise be irresistible, is circumvented. The tanks may be distorted, but the switch need not fail. Following the first rise of pressure due to the inertia of the oil, there is a further action which occurs during the generation of gases in the switch, namely, the storing

up of energy in the moving oil. If an adequate air buffer is not furnished, that oil will be brought to rest violently against the frame of the switch, and a very big force will then undoubtedly have to be dealt with. I have no doubt at all in my own mind that there are many oil switches in this country the rupturing capacity of which would be very greatly increased by baling oil out of them. They have been supplied to empirical specifications by firms who have not had the facilities for really ascertaining by experience the result of alterations in different features of the design. High pressure *per se* is not useful in oil switches. It is not a good thing to compress the arc, since this tends to make it behave as though it were a metallic conductor. One wants to allow the gases to expand. High pressure is useful only if it is utilized in some other way in the action of the switch. At the same time, experience has shown that the head of oil is a very important feature in the proportioning of the switch, and I quite agree with Mr. Partridge's remarks in that connection, and, in fact, with everything he said about oil switches. High speed is a feature which is now receiving a great deal more attention than it has done generally in the past, but clearly there is a limit to what can be done by speeding up the switch. For instance, if we speed up the switch until the stroke is completed in half a cycle, we may only just reach the zero part of the curve at the end of the stroke and we have no factor of safety on the switch at all. Switches have already been built in which that limit is very nearly reached, and I do not think that there is much more to be done in the way of speeding up. Another suggestion made in the paper for increasing the rupturing capacity of switches, namely, the magnetic method, has been tested in practice. I do not think it is generally recognized what an important part the magnetic forces play in an ordinary oil switch. The arc may be attracted very violently to the sides of the can. If the arc were situated 2 in. from the side of an iron can of infinite permeability, it would behave as though it were attracted by another arc 2 in. outside the can, so that we have conductors which commence by being 4 in. apart attracted towards each other, and it is evident that very big forces can arise under those conditions with heavy currents. The problem of explosions due to the development of gas in the switch is very important, and I think it really represents a limit of more importance than the author has appreciated. It is possible to keep down the tendency to explosion in a switch by the provision of an ample air buffer, because one thereby dilutes the gases; but when we have reached the point at which gases are beginning to be generated in such quantities as to tend to produce an explosive mixture, we have reached a point where the metal parts are beginning to be severely burned and the oil severely carbonized; so that even if the switch were built to withstand the explosive forces, one cannot expect to increase the commercial rupturing capacity beyond a certain point. Nevertheless I anticipate that we shall see big developments in oil-switch design in the near future. There are features in the action of oil switches not touched upon in this paper, and which I must not refer to this evening. It is undoubtedly a big problem to try and stop Niagara in a tank 2 ft.  $\times$  2 ft.  $\times$  4 ft., and that is the sort of problem that the oil-switch designer is being asked to solve.

Mr. G. STONEY (*communicated*): With regard to the trouble due to explosions in the tanks of oil switches, it has occurred to me that it is possible the mischief caused by these might be reduced if the sides and bottom of the tank were made flexible; for example, by corrugating them. These corrugated sides and bottoms could, if necessary, be further supported by springs or other flexible supports. What is wanted is, of course, a tank which will yield to the explosive pressure of the oil without becoming damaged; and for this purpose what is necessary is to make the sides of the tank with as little mass as possible so as to have small momentum, and so that they will gradually absorb the energy in the moving oil. It might be worth while for makers of such oil switches to experiment in this direction.

Mr. J. R. BEARD (*in reply*): The extensive interconnected system on the North-East Coast is referred to in the paper and is also illustrated diagrammatically in Fig. 8, but as one of the main advantages of such a system is the ease with which it lends itself to expansion and modification it may be of interest to describe briefly the way in which it developed. Fig. A shows it in four stages corresponding to the years 1901, 1905, 1910, and 1915. In the first stage the system is shown as it existed when commercial supply was inaugurated. As the development of the system proceeded it became evident to Mr. Merz and to Mr. Bernard Price, who was then his chief electrical assistant, that if high-pressure distribution was to be a success on the scale which they contemplated, the then existing methods of automatic feeder protection were inadequate as they would have involved a very expensive distribution system. This question became acute by the time the system had reached the second stage shown in Fig. A, when the major portion of the available load in the immediate vicinity of the power stations had been absorbed and it became necessary to look further afield. The result was the design of the system of balanced-current feeder protection with pilot wires which has been referred to in the paper. Largely as a consequence of the successful application of this, the years 1905 to 1910 were a period of very rapid expansion, during which five independent high-pressure distribution systems were linked up with the main system, sources of waste heat tapped, eight continuous-current distribution systems supplied in bulk, and numerous isolated colliery and other loads connected up over an area of many hundreds of square miles. A comparison between the second and third stages in Fig. A will show the expansion very clearly. During the last five years although the system load has continued to increase at a rapid rate, the form of development has changed from an expansion of area into a steady increase in the density of load and a consolidation of the network. The fourth stage shows the present position, and by comparing this with the third stage quite a clear idea can be obtained of the ease with which it has been possible to carry out such developments on an interconnected system.

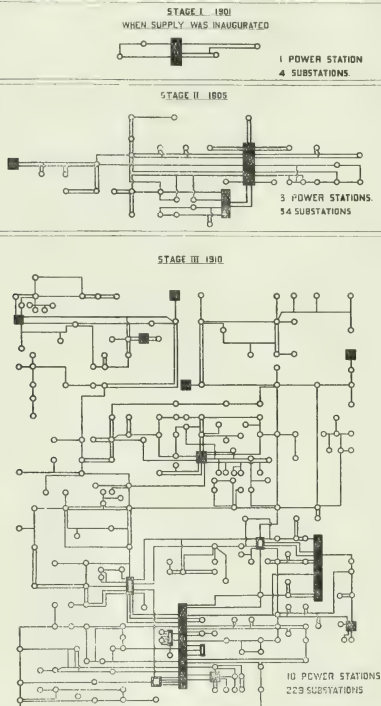
Mr. Hunter rather implied that the load factor of 50 per cent which I had assumed in my calculations was responsible for the low current densities shown in Fig. 6. Reference to Fig. 5 will, however, show that I worked out a curve for a 40 per cent load factor in order to obtain a comparison with the curve for the 50 per cent load factor, and that this made very little difference to the results. I think a 40 per cent load factor is lower than might be

Beard.

reasonably assumed for a system of the type which we hope to get in the future with a considerable diversity of load. I am very glad to have Mr. Hunter's agreement with the value I have put upon the copper losses, as the selection of a fair figure was a matter of some difficulty. The figure I finally assumed was afterwards independently checked in two ways; first, by a reference to Professor

In both cases the figure thus obtained came very close indeed to the figure which I had previously assumed. Mr. Beard.

I was very interested to hear from Mr. Partridge that in the pioneer Deptford scheme they had cable joints every 20 feet. It is bad enough to have them every 600 feet now, and the difficulties surmounted in those early days must have been very great. Mr. Partridge expressed disappoint-



## FOUR STAGES IN THE DEVELOPMENT OF THE NORTH-EAST COAST HIGH-PRESSURE DISTRIBUTION SYSTEM.

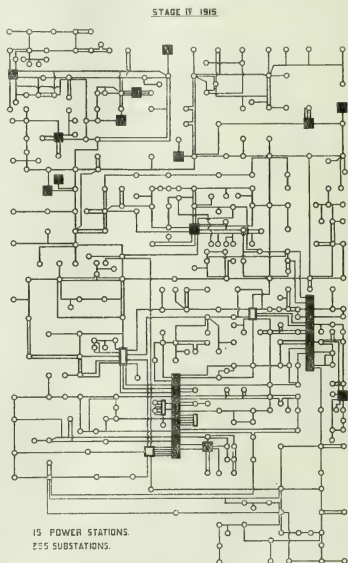


FIG. A.

Klingenberg's paper<sup>\*</sup> which was read before the Institution two years ago and, secondly, from the figures of the generating costs expected at the Barton power station of the Manchester Corporation, which were published in a paper read before the British Association by Mr. Pearce.

<sup>\*</sup> *Journal I.E.E.*, vol. 52, p. 123, 1914.

ment that I had not gone more fully into pressures above 20,000 volts. I should like to have done so very much, but I felt that apparatus above 20,000 volts is at present not sufficiently standardized to permit of a treatment based on actual costs, and that consequently for such high pressures one could only talk in generalities. In any case the curves

shown in Figs. 11 and 13 indicate the probable results of going to higher pressures. They show that under certain conditions of large areas and high density of load such high pressures may be desirable. With regard to the question of frequency, the system shown in Fig. 8 works at 40 cycles, which is fairly high. The operation of that system is very good indeed; no trouble of any sort occurs which could be attributed to using a high frequency, and rotary converters for giving a 1,500-volt traction supply are in satisfactory operation. I was very glad to have Mr. Partridge's support for spending money on switchgear and putting in liberally designed apparatus, even on small systems. My experience has been that the small system of to-day may be the large one of to-morrow, and nothing impedes the development of a system more than a mistaken economy in switchgear in the early stages. There are very few people who have had the pleasure of seeing such experiments as Mr. Partridge has described. Mr. Price in South Africa tried, I believe, a somewhat similar experiment by breaking a short-circuit on a switch fitted with a glass window in the side of the tank. I remember being told that he risked one eye to see what was going on, but I do not know if he found out much, because such things happen so quickly that it is difficult to follow them. The use of single-core lead-covered cables for all connections on switchgear and also for the busbars is novel and seems a step in the right direction. It should certainly limit the risk of damage from short-circuits and external causes and reduce the amount of cleaning required. These seem to have been the objects principally aimed at in its design, but I think it has further advantages which are of equal, if not greater, importance. First, it ensures that any fault is a fault to earth, which is much easier to deal with than a fault between phases; and secondly, it allows of the switchgear taking up the minimum of space. I should like to ask Mr. Partridge a question with regard to his system of interlocking between the isolating switches and the oil switch. Could the oil switch be closed without replacing the key and could the circuit be then made on the isolators; in other words, is the interlocking equally effective both ways? [Mr. Partridge: No, it is not; only one.] I should prefer to see the interlocking as complete as possible; otherwise there is a tendency for the incomplete interlock to cause danger owing to its producing a fallacious sense of security.

Mr. Welbourn has suggested that the figures which I have taken for the life of underground cables and overhead lines are unnecessarily conservative. I am very glad to hear this, since it is more usual for capital charges to be criticized as being too low. A reference to my remarks in the paper on this subject will show that the figures of 22½ and 17½ years were not put forward as average figures to be used for all purposes, but only as showing that the rates of depreciation which they correspond to, and which were assumed in the calculations, were on a conservative basis. It should be borne in mind that I assumed that the amounts allowed for depreciation were invested at 5 per cent compound interest, whereas I understand that municipalities usually allow only 3 per cent. With the same allowance for residual value this would give underground cables a life of 27 years, or still more if the residual value be ignored. Further, as systems extend and the design of mains develops, it sometimes happens that

certain mains are rendered unnecessary or are not up to the improved standards of the time, thus making some margin desirable for what may be termed "antiquation." Mr. Welbourn asked whether step-up transformers had been included. The only section of the paper in which this would affect the argument is that on the most economical distribution voltage. They have not been allowed for in this section as they would not have made a great deal of difference and would have complicated the problem. Their inclusion would have made the case rather more favourable for very low voltages. If the average capital cost of the distribution system is taken as about two-thirds that of the power stations, I find that the addition of step-up transformers, making allowance for both capital charges and running costs, would increase the total annual cost of the distribution system by approximately 10 per cent. The question of the maximum number of kilowatt-amperes per cable which it is now safe to transmit is not one which is capable of exact definition. It depends on three things about which there is considerable diversity of opinion, namely, the limit of voltage for 3-core cable, the maximum diameter of cable which can be conveniently handled, and the permissible extent to which insulation thicknesses can be graded with larger diameters of core. I should say at the present stage of cable development the 33,000-volt cable to carry 15,000 k.v.a., which has been referred to by Mr. Welbourn, is as far as most people would care to go, particularly since with such large cables transport difficulties necessitate comparatively short drum lengths. Joints on very high-voltage cables present more difficulty than the cable itself and it is therefore desirable to keep the drum length as long as possible.

Mr. Woodhouse added a fourth essential characteristic of the system, "adaptability for expansion." I entirely agree with the addition. When a system is laid down in the first instance, whatever type be adopted it will probably be laid out to ensure reasonable security of supply, but, as it extends, pressure of circumstances will tend to make continual inroads on the security of systems of the radial type. Such difficulties are largely overcome by the use of the interconnected system, and no one who has not actually been concerned in the expansion of a system laid out on this principle can realize the ease with which it complies with the fourth essential characteristic. While I have been in Newcastle we have added more than 200 sub-stations to the original scheme and in each case the problem has been comparatively simple. One has been left free to do what is best from the general point of view and to design the extensions so as to utilize existing copper to the fullest extent without having to trouble about how those extensions affected the operation of the protective arrangements on the rest of the system. In practice one would not lay out a system on the basis of the square, I only adopted that for my calculations on account of its simplicity, and I have no doubt that, as Mr. Woodhouse suggests, a hexagon formation might be more economical. If one refers to Fig. 8, however, it will be seen that under practical conditions the resemblance to either a square or a hexagon is somewhat difficult to trace. Mr. Woodhouse also raised the very interesting question of the desirability of two high-tension distribution pressures, say 20,000 or 30,000 volts, for linking up the area as a whole, and 6,000 or 11,000 volts for distribu-

Mr Beard.

Mr. Beard.

tion in limited areas. It would be interesting to work this out on the lines of the methods used in the paper, and at one time I had proposed doing this, but from a preliminary consideration of it I found there were so many variables that it would have been a very complicated problem. As most existing systems were laid down before the use of higher pressures than 11,000 volts was considered to be commercially practicable, such existing systems as they grow tend to develop into double-pressure systems. This is what happened on the North-East Coast, but I have considerable doubts as to whether such a scheme would be desirable for an entirely new system. Certainly in Newcastle the tendency is to make the fullest use of the 20,000-volt system and to step down from this voltage to the consumers voltage for individual supplies, thus avoiding the expense and loss of double transformation. In the case of very dense loads some modification of the ordinary methods might be desirable, but this would probably be in the direction of central switch-houses with short high-pressure feeders to adjacent transformation points connected direct to the transformers without the intervention of switchgear. Mr. Woodhouse suggests a further problem which I have not dealt with, namely, the spacing of sub-stations. This would certainly have to be carefully considered in the case of areas with very dense loads or areas with a large number of small consumers, fed at low pressure in groups from several sub-stations. For ordinary power distribution this problem does not arise, and I have therefore assumed throughout the paper that the sub-station sites are definitely fixed. Consequently it is not necessary to take account of the losses in the step-down transformers, as these are not affected by the type of system used.

Mr. Brazil dealt with the special case of very dense loads in a restricted area. The interleaved, interconnected system which he described should certainly give a very high degree of security, but I doubt whether the extra security would justify the very considerable extra cost it would entail. In that connection I should like to refer him to the figures which are given in the paper taken from the operating statistics of the North-East Coast system, from which he will note that the risk of interruption of supply is very small indeed on a properly laid-out scheme. This system is, of course, divided into a number of sections, but these are normally linked up, the arrangements being such that under very severe and extraordinary fault conditions the faulty section is isolated.

I quite agree with Mr. Wedmore that the cost of losses should be considered in buying and designing all classes of plant, but of course this must be done with discretion. It would not be practicable to make too many departures from standards on this account, since the increased cost and inconvenience of non-standard apparatus might soon more than balance any saving in losses. The question is probably worth consideration in the case of transformers, particularly with regard to the relative costs of the iron and copper losses. In connection with turbo-alternators it is already the practice of some engineers to capitalize the losses and add these to the capital costs in order to obtain a sound basis of comparison. Mr. Wedmore referred to the high pressures produced in oil switches. Some time ago we tried an experiment to see whether these were really due, as was suspected, to the inertia of the oil. An

oblong switch tank, constructed of welded  $\frac{1}{2}$ -in. boiler plate, was filled with water and two large holes were left in the top plate so that the water surface was in quite free connection with the atmosphere. A small charge of explosive was detonated in the middle of the water, and as a result it was found that the vent holes had no effect whatever; the tank was ripped along the bottom seams and the inside gusset plates torn. The explosive used was about one ounce of rippite. Mr. Wedmore also mentioned the important question of the forces due to moving oil. I know several cases in which the top plates of switches have been damaged under short-circuit, and as the oil is not normally in contact with them it seems most probable that the cause has been moving oil thrown up against them with great force. Mr. Wedmore does not think it a good thing to compress the arc. I recently noticed an article in the *Electrician*\* in support of the theory that the higher the pressure which can be developed in the arc the more efficaciously will the switch break the circuit, and I know of at least one large firm who purposely endeavour to increase the pressure. This shows how opinions on oil-switch problems differ, and how important it is that such fundamental problems of oil-switch design should be settled one way or another by conclusive experiments. I do not quite follow the argument that the limit of speed of opening has been nearly reached. The fact that the end of the stroke may be reached in the first half cycle does not seem to me to imply that the factor of safety is less than if the speed were such that, with the same length of stroke, the opening extended over several half cycles. Mr. Wedmore pointed out how the side of the switch attracts the arc. He has probably noticed, as I have several times, that the wood lining which is usually fixed to the switch tank gets badly burnt, proving that the arc has been blown or attracted towards the side of the tank as he suggests. It is not desirable, however, to get the arc too close to the tank, as this might result in a continuous arc to earth; the use of parallel arcs therefore seems the best way of utilizing the magnetic effect.

My remarks about the explosion of the gas produced while opening circuit seem to have been rather misunderstood. I merely stated that the bursting of switch tanks does not appear to be due to this cause, but I did not in any way mean to infer that the production of gases was harmless. In fact I specially advocated means for reducing the energy expended in the switch, and of course a consequent reduction in the production of gas and the burning of the metal parts. Both Mr. Wedmore and Mr. Stoney advocate flexible tanks of small mass. If the forces are really "irresistible" this would be the only solution, but, of course, although the production of these pressures is only a matter of a fraction of a second it is not instantaneous and the oil has already one free surface. Consequently once the problem is appreciated the tanks can be made strong enough. The old types of tank that gave trouble all had large flat surfaces with welded or riveted joints which gave the weakest possible construction. With round tanks designed on boiler principles the strength can be readily increased many times. It would be difficult and expensive to design a flexible tank which is flexible in all directions, and any method that allows the tank to be permanently distorted is surely wrong.

\* *Electrician*, vol. 72, p. 542, 1013-14.

Mr. Beard.

MANCHESTER LOCAL SECTION, 14 DECEMBER, 1915.

Mr. S. L. PEARCE: This paper deals with a subject of enormous importance, bearing on the question of not only cheap but reliable supplies of electrical energy, and therefore it cannot fail to be of the very greatest possible assistance to engineers engaged in the design and operation of supply systems, not as large as that referred to by the author at Newcastle, but systems which are growing and which have to deal with large and concentrated loads. I think the first point which will strike anyone reading the paper is that what I should call the old line of demarcation between the trunk feeder and the distributing main has largely disappeared in modern high-tension systems. Those of us who operate these systems know how desirable it is, in order to lay out the mains to the best advantage, that we should be able to take extra-high-tension supplies straight into the sub-stations on the consumers' premises, although to do this in the case of consumers whose demand is as small as 100 kw. (as suggested by the author) may perhaps be open to question. One point referred to by the author by way of generalization I do not think he quite means, namely, "that the cost of power is only a small proportion of the works cost." As a general statement that is not quite correct. It surely depends on the character of the works. For instance, with electrochemical plant the question of the cost of the current may be the all-essential factor and one which would weigh with the owner in determining the locality where the works should be erected. I think the author's statement wants a little qualification. With regard to switchgear, and more particularly the question of using reactances, I agree with the author that reactance coils are best used in connection with generators, although it seems to me he is somewhat doubtful as to the wisdom of their use even in that way. I would suggest, however, that the use of reactances is not simply for the protection of any individual piece of switchgear, or even an individual generator, but also and chiefly for preventing the derangement of the whole system in the event of a local fault developing, without having recourse to the method mentioned by the author of dividing the system into a number of sections, or attempting to run the whole system in a most uneconomical way. I fully agree with the author's statement that switchgear should not be proportioned to the exact capacity of the apparatus it is controlling. It is impossible to say with any degree of certitude, or to estimate the severity of the fault that any particular switch may be called upon to deal with, and therefore I agree that switches must be installed large enough (whatever the capacity of the particular apparatus they may be controlling) to deal with any eventuality. The author has based his investigations on the economical section of mains entirely on the I<sup>2</sup>R losses of the cable, and I should therefore like to show a lantern slide which gives some figures appertaining to 0.25-sq. in. cables for 11,000 volts, 20,000 volts, and 30,000 volts, and shows the problem tackled from the point of view of dielectric losses. This, I think, is interesting as indicating how the conclusions come to, in favour of the 0.25-sq. in. 30,000-volt cable and working on this basis of dielectric loss, bear out the con-

clusions of the author, who, of course, has dealt with the matter purely on the I<sup>2</sup>R losses. Figs. 6 and 7 are of very great interest indeed, and the deductions to be drawn therefrom are:—First, the higher the voltage the greater is the maximum current per phase that can be carried. Secondly, the higher the voltage the more nearly the cross-sections of the cables, determined respectively by (a) considerations of economy on the one hand, and (b) safe carrying capacity on the other, approach one another. I think that from Fig. 6 it will be seen, as regards the 20,000-volt mains, assuming that with 0.1 sq. in. cross-section a cable can carry 175 amperes, with 0.2 sq. in. 260 amperes, and with 0.3 sq. in. 350 amperes, that the safe carrying capacities from the heat-limiting point of view agree very closely with those of the 20,000-volt underground main. I will argue from those figures that as the curve for a 20,000-volt cable is still on the upward trend there is good prima facie evidence that this voltage of 20,000 is by no means the limit that can be usefully or commercially employed. The results summarized in Fig. 7 will be of the greatest possible assistance to engineers laying out new systems or carrying out extensions to existing systems. In connection with the lay-out of the distribution system, I think it will be agreed that the author makes out a very convincing case for the use of one or other of the balanced-current protective systems, but it must be always understood that this must be combined with a suitably chosen distribution voltage. I have no doubt the author has in mind the two protective systems which have been used so advantageously on the North-East Coast, namely, the Merz-Price and the Merz-Hunter; but I should like also to hear something about the Callender-Waters system, which, I believe, has been tried on one of the new electrified railways in the South. The lantern slide shows the lay-out of the Manchester system, which is nothing like so large as the Newcastle system. When the Manchester system was laid out some 14 years ago it may be taken that the system adopted was the series radial. Of course in those days no balanced-current protective system was known and this particular series radial system was adopted. We had then 20 sub-stations, and to-day with the development of the area and the industrial power load we have over 100. We have been forced to re-arrange the system both from the point of view of making better use of the copper in the ground, and also with a view to increasing the reliability of supplies by the adoption of more modern protective devices. We are making use of the existing mains wherever possible to form ring mains, with the adoption of the balanced-current protective devices, in order to employ more usefully the copper that is laid, particularly in the outlying portions of the district. I agree with the author that reverse-power relays are not satisfactory. With regard to the cost of switchgear shown in Fig. 12, it appears from the shape of that curve as though there would be an enormous difference in price between 20,000- and 30,000-volt switchgear, and I should like to ask the author whether that difference is really as great as the curve seems to show, because in going into the matter very closely some little time ago I came to the conclusion

Mr. Pearce.

there was no such great difference between those two voltages. Finally, I would say that the trend of experience with modern high-pressure distribution systems operating over wide areas and dealing with large and often concentrated loads, seems to point to the necessity, first, of choosing a distribution voltage even in excess of 20,000—in Manchester we are proposing to adopt for the Barton scheme a pressure of 33,000 volts—and secondly, of employing the largest section of cable commercially possible. If we do that we keep down the number of cables required for the system by the use of one or other of the balanced-current protective systems, and again by adopting a few number of cables we reduce the total number of switching points. And thirdly, one should dispense with, or as far as possible limit, the number of step-down transformer points on the system; which, in other words, means that the distinction between feeders and distributors is largely vanishing.

Mr. Palmer.

Mr. J. H. PALMER: It is to be regretted, I think, that the author has made no reference to the recent development carried out in connection with the balanced duplicate feeders which have been applied to a large scheme in London. It is a balanced system for utilizing reverse relays and it seems to be rather a good system.

Mr. Ferguson.

Mr. S. FERGUSON: In view of the ever-increasing capacity of their generating plant, some engineers are concerned about the breaking capacity of oil switches installed in their sub-stations. I think it can be shown that for a 6,000-volt system the capacity of the generating plant does not materially affect the initial short-circuit current that can flow into a fault in a sub-station if the feeder is of average size and longer than one mile. For the purpose of comparison let us take the case of two 0·15-sq. in. underground single-ended feeders one mile long, fed from plants rated at 20,000 k.v.a. and 40,000 k.v.a. respectively, and each having an inherent reactance of 5 per cent, the pressure being 6,000 volts 3-phase. The initial short-circuit current is fixed by the impedance of the circuit, which is made up of the reactance of the generator windings and the resistance of the feeder. I make the reactances of the above plants to be as follows:—0·09 ohm per phase for the 20,000-k.v.a. plant, and 0·045 ohm per phase for the 40,000-k.v.a. plant. The resistance of the feeder is 0·292 ohm per phase. To get the impedance of the circuit we must take the geometric sum of the reactance and the resistance, and this gives 0·305 apparent ohm for the 20,000-k.v.a. plant and 0·295 apparent ohm for the 40,000-k.v.a. plant. The initial short-circuit currents are therefore 11,300 amperes and 11,700 amperes per phase respectively. The increase in current due to doubling the capacity of the plant is thus less than 4 per cent. If the feeders were double-ended, the increase would not exceed 13 per cent. The above contention seems to be borne out in practice, since on the large Manchester and Birmingham systems it has not been found necessary to install sub-station oil switches with larger breaking capacity although the amount of plant has increased enormously. The above remarks refer specifically to a 6,000-volt system and to plant having a reactance of 5 per cent. Variations in the pressure and reactance of the plant would of course modify the position. With increase of voltage (other factors remaining constant) it will be found that, for the particular length of feeder

mentioned, the short-circuit current is more directly dependent on the plant capacity than in the case cited. When considering distribution at 20,000 to 30,000 volts the breaking capacity of sub-station oil-switches will require careful consideration, as the power flowing to a fault varies as the square of the voltage, so that at 24,000 volts a switch would have to deal with 16 times the power obtainable under the same conditions with 6,000 volts. Reference is made in the paper to interlocks. I think the most important interlock on any cubicle is the one dealing with incoming feeders. An attendant can satisfy himself that he has made the switchgear dead from the busbar side, but he cannot answer for the man at the other end of the feeder. It is therefore necessary that some means should be provided for earthing the feeder, or, if this is not practicable, for locking the feeder isolating-switch chamber. The author mentioned that the number of potential transformers should be reduced to a minimum. I quite agree with him, as they are undoubtedly the weakest point in any switchgear system. I am afraid, however, that very few engineers would be prepared, on account of the expense involved, to adopt his suggestion to protect such transformers with an oil switch, although in some cases the extra security provided would warrant it.

Professor E. W. MARCHANT: For some time it has seemed to me that while much attention has been paid to the machinery of generating stations far too little has been given to the distribution system, which, after all, represents a large percentage of the capital outlay and therefore deserves equal consideration. In the first place I should like to ask the author a question with regard to the note on page 127 about the voltage-drop with the split-conductor system of protection. I should have anticipated that there would not have been a very great difference between a system of overhead lines run in the ordinary way and one with split conductors, and I should be very glad if he would give some data as to the extent to which the voltage-drop on the split-conductor system is reduced. With overhead lines, of course, the inductive drop depends on the distance between the wires and also on the cross-section of the cable. I mention this because it is not referred to in the paper. It is one of the points in which aluminium shows to some slight advantage as compared with copper. The author mentioned the danger due to the swaying of the overhead wire in the wind. When I was in America some years ago I saw a number of very long spans, some extending to a third of a mile, and I was told by the operating engineers that no difficulty had been experienced with the swaying of the wire, even on the longest spans. I should like to refer to what the author said on the question of the most economical section of mains and the curves given on page 132. If we work out the relation which exists, by what is generally known as the Kelvin law of economy, we shall find that the current density in the cable does not depend upon anything except the cost of the cable, the resistance of the material of which the cable is made, and the cost of energy per unit. If  $\rho$  is the resistance of the material in ohms per mile of conductor of 1 sq. in. cross-section,  $s$  the cross-section of the conductor in square inches;  $W$  the cost of one watt-hour; and  $t$  the time in hours for which the cable is running at full-load current ( $I$ ) during a year, then the cost of the wasted

Mr. Ferguson.

Professor Marchant.

energy per mile of cable is  $\rho I^2 l / W$  s. Let  $\beta$  be the fraction of the capital outlay allowed for interest and depreciation. The charge for interest and depreciation on the capital cost per mile of cable is  $\beta(K_i s + K_v)$ , where  $K_i$  and  $K_v$  are constants depending on the type of cable or overhead line. The copper loss in the cable is equal (by the Kelvin law) to  $\beta K_v s$ , which represents the charge for interest and depreciation on that part of the capital cost of the cable which is proportional to the cross-section of the conductor. Taking this result we get

$$\rho I^2 l / W = \beta K_i s, \text{ or } \rho I^2 W \left( \frac{l}{s^2} \right) = \beta K_i;$$

that is, the current density ( $I/s$ ) depends simply upon the constants  $\rho$ ,  $\beta$ ,  $K_i$ ,  $l$ , and  $W$ ; 100  $\beta$  is the percentage charge for interest and depreciation,  $K_i$  a constant depending upon the cost of the cable per sq. in. cross-section, so that the economical current density in a cable of a given type is constant, according to the Kelvin law, and if we look at the author's tables we shall see that this is so. For overhead mains, the curve showing the relation between current and cross-section of wire is a straight line—that is to say, the current density is the same for all sizes of cable—and with the curves for cables there is a straight-line relation also. As the voltage increases,  $K_v$  will increase because we shall want more insulation upon the cable; the result is that the most economical current density for the cable will also increase. That is also shown by the author's tables, because the current density for a 20,000-volt cable is considerably greater than with a 10,000-volt cable, and so on. It is clear, from this result, that if we increase  $K_i$  enough—that is, if the working pressure be increased sufficiently, and we have adequate insulation—we shall reach the point where the economical current density corresponds with the heating limit. The Kelvin law is not a sound law for determining the most economical current for a cable already laid, and for such a cable the basis of the law is clearly wrong. The basis on which the Kelvin law is founded is minimum total charge for energy distribution; the best basis for a cable already laid is for a minimum ratio of the total cost of producing energy to the revenue earned. If this basis be taken, it may be shown that the most economical current for a cable is that for which the cost of the waste energy is equal to the total charge for interest and depreciation on the cable. On this basis the economical current density will be somewhat greater than that determined by the Kelvin law; as a rule, however, the difference between the two is not very great.

Mr. G. HARLOW : The question of the size of the primary windings of series transformers is one which is very often overlooked in large-capacity systems until experience proves it to be the most essential point, since within the past two or three years I have known several serious cases of overheating on instantaneous short-circuits which has been due to this trouble. One case in point occurred on an 11,000-volt, 3-phase system with a generating capacity of approximately 20,000 kw. On this system the standard practice was to protect a 50-k.v.a. or 100-k.v.a. transformer by means of an oil switch with the series transformer operating the trip coil of the oil switch and in some cases having an ammeter in circuit. The ratio of the series

transformer for the 50-k.v.a. distributing transformer was 4/5 amperes, the current density in the primary winding being approximately 1,650 amperes per sq. in. This current density in the primary windings gave, of course, no overheating at either full load or overload conditions, but in one or two cases where such apparatus was installed near to the generating station, and where a high-tension fault occurred beyond the series transformer, the amount of short-circuit current passed through the fault was sufficient entirely to destroy the series transformer and cause a great deal of damage in the sub-station. For instance in one or two cases the short-circuit current which could be obtained beyond the series transformer was 6,000 amperes, and in passing such a current through the series transformer the current density in the primary winding of the same was in the neighbourhood of a million amperes per sq. in. This current density is sufficient to raise copper to approximately 1,200° C. in one second, the natural result being that the series transformer exploded and a good deal of molten copper was thrown about the sub-station. Assuming that the oil switch was fitted with a time limit of any description, then the situation became very serious indeed. Even assuming that the oil switches were without time limits and opened in  $\frac{1}{2}$  sec. from the commencement of the short-circuit, the copper in the series transformer would be somewhere in the neighbourhood of 400° C. After investigation the system of protecting the main transformers was altered and the rule used in specifications with which the author is associated has been adopted. That is to say the primary winding of the series transformers is always made of approximately the same section as that of the main with which it is connected. Such an arrangement involves the use of a relay for tripping the oil switches unless the series transformers are to be made unduly large and expensive. A point raised by the author in connection with the use of potential transformers on the busbars is most important, and he is undoubtedly right in stating that for all large stations potential transformers should always be protected by means of an oil switch. It is rather remarkable that more stations are not shut down due to the use of potential transformers on the busbars than is actually the case, the reason being due, I think, to the fact that the faults on potential transformers are usually between turns at points away from the terminals, so that the impedance of the potential transformer turns reduces the amount of fault current and enables the standard fuses to clear the fault. In spite of this consideration there is no doubt that the danger due to a fault on the end turns of potential transformers is a very serious matter and only large oil switches could possibly deal with such faults. Another most interesting point is that of the opening speed of oil switches. The opening speeds of oil switches during the past few years have been greatly increased, and I was rather hoping the author would be able to give some figures in connection with this, since makers have been competing to a great extent on the speeds at which their oil switches open. Perhaps the author could give us some indication of the minimum speed at which oil switches for large-capacity stations should operate. The question of utilizing the magnetic force to increase the length of the arc and the breaking capacity of the switch is extremely interesting and several expedients have been adopted with some degree of success, but as far as I know no tests have been made

Mr. Harlow.

Mr. Harlow. and no figures obtained which will lead to any definite conclusion on the point. Some makers of oil switches so arrange their designs that the moving parts are as light as possible, in order that the inertia may be small and the speed of opening increased due to the magnetic forces exerted by the short-circuit current. Other makers work upon the principle that the moving parts must first of all be mechanically strong, and rely upon springs in order to secure a rapid speed of opening. At the present time it would seem that no definite stand has been taken up by users of oil switches as to which method of designing the switches is preferable. The danger in the first method of switch design seems to be in the tendency to make the moving parts so light (in order to reduce the inertia) that they do not remain mechanically sound during years of operation. The author remarks that vent pipes will not increase the breaking capacity of the switch, and this is of course true; but nevertheless I believe he is of the opinion, like most people nowadays, that the vent pipes are very desirable on oil switches. It is true that they do not relieve materially the pressure on the switch at the moment of opening, but they do get rid of the gases formed at the top of the switch, and this seems to me a most essential point, since should a switch be closed for a second time on a bad fault the fact that the gases at the top of the switch have means of egress from the tank certainly reduces the strain on the switch while opening the second fault. The question of interlocking switchgear still seems to be a matter for individual judgment. We may either rely on our operating men or on our mechanical interlocks, but the best of operating men make mistakes occasionally and it is also nearly certain that in the course of years mechanical interlocks will occasionally fail; and the conditions then obtaining while not necessarily fatal are certainly dangerous, since the operating men are given a false sense of security. In newly designed power stations it may in many cases be possible to do without reactances in feeders, since we can put sufficient reactance in our generator circuits and busbar circuits to know exactly the maximum short-circuit current which feeder switches should be expected to clear. There are many existing stations, however, where it would certainly pay to use reactances in the feeders. A case I have in mind is that of a large municipal station in this country with approximately 10,000 kw. of generating plant. There were several large feeders radiating from the station and a fault occurred on one of these feeders (or 1 sq. in. section) approximately a quarter of a mile from the generating station. At the point where the fault occurred it was quite possible to get through the feeder a short-circuit current of 10,000 amperes, which is sufficient to raise the copper in the feeder and in the joint boxes at the rate of 120 degrees C. per second. There were 3-second time limits on the oil switches in the case under consideration, and the temperatures obtained before the oil switch cleared were sufficient to cause trouble not only on the joint boxes of the particular feeder on which the fault occurred, but also on other feeders which were working in parallel with the faulty feeder. Under such conditions a 5 per cent reactance in the feeders would limit the short-circuit current to 2,000 amperes on each feeder and render the conditions of working absolutely safe. Under such

circumstances as these, and there are several stations in the country working under these conditions, it would certainly pay the operating engineers to use reactances in their feeder circuits. I think the above also deals with the point raised by Mr. Ferguson earlier in the discussion as to the amount of short-circuit current which can be expected at comparatively short distances from the generating station. The 0.15-sq. in. feeder mentioned by him will pass 20,000 k.v.a. over a 6-mile length assuming the voltage at the generating station to be maintained, and such a figure as this proves conclusively that within anything like a radius of two or three miles of a 6,000-volt large-capacity generating station the oil switches in the sub-station ought not to be of smaller capacity than the generating-station switches. A question has been raised with regard to the Callender-Waters system for the protection of mains. I do not know whether any later developments of this method of protection have been recently introduced, but I saw preliminary tests on this gear. As then arranged it was intended to deal only with faults to earth and not with faults between phases. It seems to me that any system which only deals with faults to earth is merely an expedient to avoid the use of the existing efficient systems of protection such as the Merz-Price and the split-conductor systems, and will certainly not be put into commercial use. It is, of course, quite true that by far the greater number of faults on any cable system are faults to earth, but such faults can be easily dealt with, since they can be limited by means of a resistance in the neutral point of the system. The real faults which matter on a large-capacity system are the faults between phases, since these tax the capacity of the generating plant and the oil switches, and an efficient system of protection must deal with such faults. I should be glad if the author could tell us how much split-conductor cable is in use on the North-East Coast system. I know that during the past year or two most of their extensions have been carried out on this system, and by now they must have laid down a considerable mileage of mains. I should also be glad if he would tell us whether they have definitely decided to use split switches on all future work.

Mr. A. F. W. RICHARDS: I am especially interested in Figs. 5, 6, and 7. These show the financial advantage of installing plenty of copper when laying mains, as it will be seen that, after determining the most economical section, the cost (when reckoned in losses and interest per annum) of making ample provision for future requirements is almost negligible. Another point which is very clearly shown in Fig. 7 is that overhead mains at pressures up to 6,000 volts are not a paying proposition for transmitting power not exceeding some 400 to 500 kw.; this is, of course, only true so long as there are no other considerations to be taken into account, such as shortening of route, etc. In the preparation of these curves, however, there is one point where I can scarcely agree with the author. At the foot of column 1 on page 131 he assumes a 50 per cent load factor for his station, and a load factor for the whole of the network of 40 per cent, and considers that he will get almost a 50 per cent factor on the mains nearest the power station. Surely if he is to get a 50 per cent load factor on both plant and main feeders, he is assuming a diversity factor on his network of 100 per cent,

and this appears to me to be an impossibility. It would be interesting to know if the author has ever experienced in practice a load factor throughout his network of anything approaching 40 per cent. I admit that this is a matter of minor importance, since in Fig. 5 he has shown that the load factor of the system has little or no bearing on ascertaining the most economical section of cable. A point in connection with Fig. 6 which I think is worthy of attention is that the top curve shown in this figure has to be based on the German Rules. Although the subject of "heating effects on underground cables" has often been discussed before the Institution, a great deal of data is still wanted on this subject. If the author could give a few figures showing the difference in inductive drop on ordinary 3-core mains and split-conductor mains respectively, they would, I think, be of great interest.

Mr. S. J. WATSON: The first point I wish to emphasize is the ease with which sub-stations can be set up when high-pressure distributing mains are adopted. In the past in connection with continuous-current systems we often had to lay low-pressure mains to a considerable distance from the power stations, and difficulties of regulation and of giving a proper pressure to consumers frequently arose; but when a high-pressure system is in use it is perfectly easy, as the author points out, to set up sub-stations wherever they may be applied to the greatest advantage. Many of the difficulties previously existing on continuous-current systems are therefore entirely overcome. There is, however, in connection with such sub-stations a point which is worthy of consideration by designers, and that is to devise some cheap and reliable automatic regulator which can be used on the secondary side of transformers, especially where the sub-station deals with an appreciable load which varies from time to time. There are, as far as I know, only two means available at the present time, both of which are exceedingly costly. The first is to take tapplings from the transformer on the secondary side to a multiple-contact regulating switch, and the second is a sort of auto-transformer with movable fields. Both of those methods are costly; and at the same time they are not automatic and require hand regulation. The author has gone to very great pains in preparing this paper, but I am afraid in many cases the determination of the section of conductors on high-pressure systems is not worked out on the scientific methods which are set forth in the paper. Most systems, whether for high pressure or low pressure, have usually been started more or less in a small way. When the mains were laid we had but little idea where the load was going to be obtained, or if we had we usually found it did not come in the particular place where it was expected. The practice which has usually been adopted has been to fix on a certain section of copper and to lay the cables in the directions where the chance of obtaining the load seemed the most promising. If we compare Figs. 8 and 9 we see quite clearly the difference between what has turned out to be a practical lay-out and various theoretical lay-outs which may arise. We never by any chance get the generating station in the centre of the network; it is either at one corner or altogether outside the network. It never comes in the place relative to the distribution system where we should like to have it, and this fact appreciably affects not only the original lay-out of the system but also any develop-

ments in the way of modernizing it from time to time as the output increases. In regard to the question of protective devices, the author mentions several which have mostly been introduced in the last few years, but I should be glad if he could tell us the system originally adopted on the North-East Coast for the protection of the mains. Another point is in connection with the use of loop mains and alternative methods of duplicate feeders. It may, I think, be said that most systems of supply consist of a central area, more or less dense in its demands, with other areas jutting out into the "wilds." For instance, in my own town the potential consumers are distributed somewhat in the form of a star; there is a fairly good demand adjacent to the main roads running out of the town, but between the tips of the star there is mostly waste land. It is clear, therefore, that in an area such as that we cannot adopt, on account of the cost and the large amount of cable which would remain idle, a system of ring mains running round the outskirts as shown on several of the diagrams in Fig. 9. Another important point is the small difference in cost of  $2\frac{1}{2}$  to 5 per cent, which enables an engineer to increase the capacity of the cable by a very large percentage. I think that is a point which may very well be borne in mind, because eventually a slight increase in the amount of copper is usually found to be a sound investment. The system which is described in the paper is, of course, a very extensive one, and, as the author shows, it consists of some 15 generating stations and about 350 sub-stations. The conditions which obtain on such a system are rather different from those that most of us who are in smaller towns have to deal with. Finally, I think the matter of laying out distributing systems in common with other design work is most ably summed up in the concluding paragraphs of the paper where the author states that, with whatever care we make our calculations, there are so many points which come into the question that we may very easily find some little thing has been overlooked which vitally affects the successful operation of the system as a whole.

Mr. F. FERNIE: There are one or two questions I should like to ask. Does the author exclude cables from the statement on page 126 "that no apparatus can be made immune from breakdown through external damage"? With all the accumulated experience that has been gained it seems rather deplorable if the confession has to be made that cables cannot be made immune from breakdowns, particularly as the author says in another part of the paper that where there is danger of subsidence of the ground he uses overhead mains. It may be said that nobody can guard against damage to underground cables from workmen opening up the roads and doing repairs, etc. I know a case, however, where this kind of damage was almost entirely prevented by the supply authorities receiving a copy of all permits granted to break the road in any way, so that they could send an inspector to point out to those opening the road exactly where the cables were. Fig. 7 shows the annual cost per mile of cables and overhead lines for 20,000 volts. It is rather difficult to criticize the figures without knowing the class of work they represent. I have read somewhere that it was proposed at Newcastle to use some 11,000-volt cables at 20,000 volts. I do not know whether this has been done, but supposing that it were done I should like to ask the author would the 20,000-volt

Mr. Fenie. line of underground cable in Fig. 7 coincide with the 11,000-volt line. This, of course, brings in the question of the factor of safety of a cable. I should be glad if the author would say what, in his opinion, is the minimum factor of safety permissible for a cable. The factor of safety, of course, varies with the diameter of the conductor. On some of the 20,000-volt cables used in the Newcastle district the factor of safety was of the order of 7 to 8, while on some of the 11,000-volt cables the factor of safety was 10 to 15. By factor of safety I mean the ratio of the maximum stress at which a cable will break down to the maximum stress at which it is worked. Returning to Fig. 7, I should be glad if the author could explain why the inclination of the 20,000-volt line is different from that of the 11,000-volt line. If we assume the curves are straight lines, which they are approximately, and work out the equation  $y = a + bx$  for each, the value of  $b$  for the three parallel lines is about 0.6 and for the 20,000-volt cable about 0.8. I do not understand why  $b$  should be different for the 20,000-volt cable. On page 140 it will be noticed the author considers that for economical reasons alone the distribution voltage will be raised above 20,000 volts. There seems to be no reason at all why a cable should not be built for very much higher voltages and still be of practical dimensions. Of course all depends on the factor of safety that is demanded.

Mr. Morton. Mr. J. A. MORTON (*communicated*): This paper is the first full and scientific treatment I have seen of the principles underlying the design of high-tension distribution systems. The importance of this subject can be appreciated when one remembers the proportion the distribution system bears as regards cost to the total cost of a scheme, and the losses which take place in it. The difficulty in applying these principles to the design of a new system is that one cannot be certain of the preliminary data such as the actual load factor of the system and the cost per unit, although approximations can usually be obtained from similar systems already in operation. As the author states at the end of the paper, "theoretical calculations must be used with caution," and it is fairly obvious there are usually considerable limitations. Many high-tension distribution systems have grown up by a process of accretion, and it is often difficult to graft higher pressures on the system later. The tendency during recent years, as the author points out, has been to increase the voltage of the systems, but this has been due not so much to any scientific or logical reasoning, but chiefly to the pressure of circumstances. The consequence has been that engineers have often selected a lower high-tension voltage than should have been adopted. Naturally there has been a conservative tendency to keep the voltage on the low side on account of unfamiliarity, safety of apparatus and cables, etc., but there is no excuse for this at the present time when apparatus and cables designed for 10,000 volts are just as reliable as those designed for 3,000 volts. There are, I feel sure, high-tension distribution systems in this country working at 3,000 volts where 6,000 volts would be better, and at 6,000 volts where 10,000 volts would be better. Coming to the details in the paper, in Fig. 1 a suitable allowance has been made for trench work for the underground cables and for wayleaves in the overhead line. Assuming, however, that other considerations have already decided whether a main is to be

overhead or underground—which is usually the case—Mr. Morton then the cost of trenching or wayleaves can be omitted altogether, because in comparing one size of cable with another the trenching cost is the same for any size of cable. Only when cables are to be compared with overhead lines is it necessary to take the wayleaves and the trenching into account in the annual cost in order to get a fair comparison. With regard to Fig. 6, it is interesting to note how near the economic cross-sections come to that mystic phrase "1,000 amperes per square inch," which one still meets occasionally in specifications. It almost looks to a superstitious person as if there were something in this arbitrary phrase. On page 138 the author suggests  $7\frac{1}{2}$  per cent as a maximum working voltage-drop, but for any load factor up to 50 per cent I should feel quite safe in allowing a 10 per cent drop in the mains alone, so far as a reasonable voltage variation is concerned. With regard to Fig. 10 on page 139, my experience is, in the case of underground cables, that inductive drop may be ignored in working out the voltage-drop. Underground cables have considerable capacity, and one can usually assume that the capacity of the cable, by slightly raising the power factor, nullifies what little inductive drop there is. There is one point I do not see mentioned in the paper, and which seems to me to be important. In comparing say a 20,000-volt transmission with a 6,000-volt or 10,000-volt transmission it must be remembered that one can generate and distribute direct to consumers or sub-stations at the two latter pressures without any step-up transformers at the generating station. If, however, 20,000 volts is to be used, this means step-up transformers at the power station, and these involve considerable outlay. They are really part of the 20,000-volt distribution system and the cost of them should be taken into account in comparing the cost of the 20,000-volt main with a 10,000-volt main which needs no step-up transformers. If this is done, it may be found that the lower voltage is the most economical, whereas if the cost of the step-up transformers on the 20,000-volt transmission be ignored, the latter voltage may seem to be the economical one. It seems to me that this is a point to be borne in mind. It is, however, quite true, as the author says, that generally speaking the heavier the load the higher is the economic voltage, other things being equal. A little time ago I made a comparison between 20,000-volt 3-phase trunk mains and 50,000-volt trunk mains, the maximum kilowatts to be delivered being in the neighbourhood of 28,000, the power factor of the load about 0.8, the frequency 50, the length of route 30 miles, and a 50 per cent load factor. I found that by using 50,000-volt cables there would be a net annual saving of about £10,000 in favour of the 50,000-volt scheme. In this instance, I not only took into account interest, depreciation, and I<sup>2</sup>R losses in the cables, but the extra cost of 50,000-volt switchgear and transformers, the extra copper losses in the 50,000-volt cables due to the capacity current, and the extra dielectric losses in the 50,000-volt cable due to hysteresis. This investigation also brought out the important fact that at the average load the power factor at the generating end was 0.96 due to the electrostatic capacity of the cables themselves, this capacity being obviously very useful in this case where the power factor of the load was only 0.8. The examples dealt with in the paper relate to distribution systems, but the

same methods can be used in laying out ordinary trunk mains.

Mr. M. MENBAUM (*communicated*): Regarding the split-conductor system, it appears to be the usual practice to earth only the feeders, the earthing switch being interlocked with its corresponding oil switch, and not to employ isolating switches, the object being apparently to minimize the number of variable resistance contacts. With the draw-out type of switchgear these variable resistance contacts exist and I should like the author to state why, if the latter be successful, isolating switches with earthing contacts could not be adopted in the former case as being distinctly advantageous, in that the oil switch is completely isolated and can be safely handled even though the other end of the feeder may be inadvertently made alive, since in practice it is the oil switch or instrument transformers which require overhauling and adjusting. In order to prevent the feeder being inadvertently made alive from the sub-station end, it is advisable, and I think the usual practice, to provide locks on the switches so that they can be locked in the "off" position. Regarding the question of the breaking capacities of oil switches, it is interesting to note that a Continental firm employs special enclosed chambers surrounding the fixed contacts, so that the pressure of the gases in these chambers formed on opening materially increases the rate of rupture and thus the breaking capacity of the switch. A switch of this type is said to have broken the circuit in one half a period on a 50-period circuit, that is in  $1/100$ th of a second. With reference to the economic employment of copper on a system, although calculations in line with those mentioned by the author can with advantage be made, yet it is very difficult to fix on the constants of the system, since these are liable to vary as the system becomes increased. For instance, the cost of generation and the probable load curve of the feeder have to be assumed, and it is quite an easy matter to go wrong with these factors, which vary as the system expands. It would be interesting if the author would give comparative prices for the balanced-voltage and split-conductor systems per mile of feeder, and also figures for ordinary against split-conductor feeders (both underground and overhead). There is no doubt that discriminative features should be adopted to a greater extent than at present for both high- and low-tension systems in order to cut off a faulty section with a minimum interruption to the supply; and it seems to me that this has been especially neglected on low-tension networks, as in many cases a temporary stoppage of supply has resulted in a large financial loss to the consumer, such loss representing more than the cost of these discriminative devices.

Mr. H. A. RATCLIFF (*communicated*): The paper is a very concentrated one, and the enormous amount of work involved in its preparation is better appreciated after a careful study of the valuable sequence of curves dealing with distribution losses and economical current densities, etc. It is doubtful whether it is always possible to lay out a system with the mathematical precision outlined by the author, and consequently in many cases expediency is necessarily the predominating factor in the calculations. In this connection, the author very aptly quotes from Professor Schuster's Presidential Address to the British Association. The author several times emphasizes the

advantages of having a high supply pressure, and in fact does not fix any upper limit; but, nevertheless, for certain reasons, he restricts the scope of the paper to a range of 20,000 volts. It would be interesting to know of the difficulties incidental to the employment of higher pressures, because values as high as 30,000 volts are likely to be used in the near future. No reference is made in the paper to dielectric losses, and therefore presumably the author considers them to be of negligible amount within the range of pressures dealt with. This will not, however, be the case at pressures appreciably higher than 20,000 volts, and the question of suitable current density will then no doubt be governed to some extent by the existence of such losses, although mere considerations of economy may permit increased current densities at the higher pressures (as shown in Fig. 6). The reason for this is that the dielectric losses increase rapidly with increase of temperature, and consequently they may attain dangerous proportions under load conditions if the current density is at all excessive. The economic advantages of an inter-connected system are very conclusively illustrated; this is not surprising, since somewhat the same result was arrived at many years ago in connection with large multi-wire low-tension continuous-current networks. The more they were interconnected, the less the voltage-drop, and the better the regulation and balancing; but the location and clearing of faults was a difficult process, and if they were serious, it usually meant shutting down the whole system. The various discriminating protective devices now available, however, have overcome to a great extent the difficulties incidental to the interconnection of a high-tension system. Referring to the subject of switchgear and accessories, I think that in most cases it is the extent of the current, rather than the pressure, which causes trouble under abnormal conditions, and therefore the higher the pressure of supply, the smaller are the currents to be dealt with, and the simpler are the problems connected with the design of satisfactory switchgear. There is no doubt that the switchgear is frequently the weakest link in a system, and the author very wisely emphasizes the importance of making a good job of it regardless of expense. Insufficiency of copper on the primary windings of current transformers is mentioned as a likely source of trouble, and it would be interesting to know if this is a usual experience. Judging from experience with hundreds of transformers, I should say that it is very unusual, and that a more common occurrence is short-circuiting of the primary turns by high-frequency discharges. To employ more copper in the windings means either larger and more expensive transformers or else a reduction in the ampere-turns, which is undesirable.

Mr. J. B. PALMER (*communicated*): On page 129 the author remarks on the fusing of connections by the heavy currents which flow under short-circuit conditions, and refers to the necessity for current-transformer primary windings to be of heavy section. It is becoming more frequent to find in switchgear specifications a clause to the effect that the cross-section of the primary windings of current transformers must not be less than the cross-section of the feeder to which they are connected, and this policy will doubtless become more general when the importance of it is more fully realized. The problem is, of course, one of space, and when one considers that in

Mr. Ratcliff.

Mr. Palmer.

Mr. Palmer. an installation of, say, a 100-k.v.a. transformer at 11,000 volts, the normal full-load primary current of which is in the neighbourhood of 6 amperes, the current transformers would be required to have sufficient volt-ampere capacity to supply an ammeter, overload relay, and possibly a watt-hour meter (all requiring close accuracy), the space required for three such current transformers is a factor which would materially affect the design of the cubicle. The tendency at present is to design oil-break switches which will deal with the short-circuit power of the system without relation to the normal full-load current, as mentioned elsewhere in the paper; and since cubicles are undoubtedly being made larger than hitherto in order to accommodate large oil circuit-breakers, the difficulty as regards space should automatically solve itself. From the point of view of mechanical design and insulation, it is probable that the stud or bar primary type of current transformer is the most desirable, and for use with sensitive relays such as are employed with the Merz-Price and split-conductor systems, there is nothing to prevent the adoption of this type. In the case, however, of current transformers for ordinary switchboard service, the bar primary is almost precluded for primary currents much under 300 amperes, and I think that if any progress at all in the design of current transformers along these lines is possible, it will have to be preceded by a departure from the accepted designs of meters and instruments as regards their power consumption.

Mr. Beard. Mr. J. R. BEARD (*in reply*): As the system which Mr. Pearce controls is, I believe, the second largest high-pressure distribution system in this country, I am very glad to find that as a result of his experience he is able generally to confirm the conclusions of the paper. He rather queries the desirability of giving direct high-pressure supplies to consumers whose demand is as small as 100 kw., and if a number of such consumers are in close proximity to each other it is quite probable a case could be made out for low-pressure distribution over a limited area from a common sub-station. It is all a question of the density of load, and in the case of isolated loads where there is no alternative to the direct high-pressure supply it has been found quite a commercial proposition to connect up consumers whose demand is 100 kw. and even less. The small consumer naturally has to pay higher rates than the large one, as the cost of connection is higher per kilowatt of maximum demand, but if the high-pressure network is sufficiently extensive the supply authority can readily compete with a private plant.

My statement "that the cost of power is only a small proportion of the works cost" does, I agree, require some qualification, and as pointed out by Mr. Pearce it does not hold in such cases as electrochemical industries. In making this statement I had in mind the usual types of industrial load such as collieries, shipyards, mills, etc. I am sorry if my remarks cast any doubt on the desirability of reactance in generators. I did not intend this as I consider its use in this connection most desirable. Owing to the satisfactory operation of modern automatic voltage-regulators, there is in practice no objection to reactance in the generators except that the generators have to be larger in order to allow for the increased regulation which is necessary. Such reactance is, of course, not only useful for protecting the individual generators, but also for limit-

ing short-circuit currents on the system and preventing derangement under fault conditions.

I was much interested in Mr. Pearce's lantern slide showing the effect of the dielectric losses, and it is satisfactory that this bears out my conclusions. This slide also justifies my statement that up to 20,000 volts the copper losses are the only losses which are important enough to be taken account of in a consideration of the economical section. From the slide I see that in the case of 20,000-volt cables the dielectric loss based on a price of 0.4d. per unit only represents one-ninth of the total annual cost. Since the dielectric loss has a 100 per cent load factor 0.4d. per unit is much too high, and personally I should have hesitated to have put it at much more than 0.15d., this figure being comparable with the figure of 0.25d. per unit which I have taken for the copper losses. Making this modification to the cost of the dielectric losses it will be seen that they only represent about 1/25th of the total annual cost even at so high a voltage as 20,000, whereas the copper losses work out to about one-third.

Mr. Pearce referred to the Callender-Waters system of feeder protection. In its original form this was only operative for faults to earth, but possibly modifications have been made which remove this defect. As Mr. Harlow pointed out later in the discussion, the real faults which matter on a large-capacity system are the faults between phases and it is these which should be most speedily removed. Like the split-conductor system it requires a special form of cable, and provided that the system can be made equally as reliable and convenient, and also provided that the special cable can be made more cheaply, it strengthens still further the arguments in favour of the interconnected system. I have seen no figures of the cost of the special cable, but I doubt if it is likely to be cheaper than split-conductor cable in view of the cost of the inactive copper in the tapes. Split-conductor cable has also the advantage that the extra insulation is in a position where it is beneficial to the stress distribution.

With regard to the question of the cost of switchgear, it must be remembered that, as the voltage increases, the spacing of conductors and the thickness of insulation, etc., increase at a rate more than proportional to the voltage. This is clearly shown in the case of cables. Consequently I think that for the same current it is probable that the curve shown in Fig. 12 would continue to rise. It is permissible to plot this curve for the same current, since whatever voltage be adopted the average current-carrying capacity of the feeders does not differ widely as far as the sub-stations are concerned.

If the price of the switchgear is considered as so much per kilovolt-ampere controlled, it will be found that the cost shows some decrease as the voltage increases. In the case of power-station switchgear the conditions are somewhat different, since the output of the generators will be the same whatever the voltage; it follows that with a low voltage the current-carrying capacity of the switches must be correspondingly higher. Switches for heavy currents are undoubtedly expensive, and for these special conditions I have no doubt that low-voltage switches might be as expensive as high-voltage ones.

Mr. J. H. Palmer referred, I think, to the Ferranti-Waters system of parallel-feeder protection. I did not deal with this in the paper because at the time it was written this

system was only in the experimental stage, and it still has not, I believe, been tested in practice under such onerous conditions as either of the systems of feeder protection which I mentioned. Even if it proved able to stand up against the enormous straight-through short-circuit currents of a large system and to discriminate perfectly between the faulty and sound feeders under all conditions, it could not in general be justified on financial grounds. The reason for this is that, as in all similar forms of parallel-feeder protection, two separate cables have to be laid along each part of the route and this is not compensated for by an equivalent reduction in route length. I have worked out the annual cost of the typical system referred to in the paper on the basis of its being laid out for this form of protection, and I find that without allowing anything for the cost of the protective apparatus it would be over 18 per cent greater than the annual cost of the corresponding interconnected system. In its technical aspect this, like all forms of protection which operate on the reversal-of-power principle, requires potential transformers, the multiplication of which is a source of weakness to the general system.

Mr. Ferguson makes rather an interesting point regarding the effect of increased capacity of generating plant on sub-station switchgear, and, on the assumptions which he has made, his figures are of course quite correct, but I cannot agree with all his deductions. I imagine the average inherent reactance of both the Manchester and Birmingham systems is more than 5 per cent, owing to the large amount of low-speed plant originally installed. Since all the new plant consists of low-reactance turbo-alternators the conditions become more severe for the switchgear than would be the case if one simply considered the increased generating plant on a k.v.a. basis. Probably also the old sub-station switches to which he refers are very sluggish when starting to operate and therefore do not have to break anything approaching the maximum short-circuit current, with the corresponding disadvantage that the system voltage will be nearly wiped out and the system badly deranged before the fault is cleared. Taking Mr. Ferguson's own figures the short-circuit current at a sub-station with duplicate 0.15-sq. in. feeders one mile long would be of the order of over 23,000 amperes, and only a very carefully constructed switch would be capable of dealing with this. With the quite likely case of several 0.25-sq. in. feeders this would be still further increased, and also at such low voltages as 6,000 many sub-stations will be within the one mile radius of the power station. In any case I do not think we shall see many more large systems at such a low voltage; and with the higher voltages, as Mr. Ferguson points out, sub-station oil-switches will have a much severer duty.

I am glad to have his approval of the interlock between the door of the incoming feeder cubicle and the feeder earthing-arrangements. In the many imperfect interlocking arrangements on the market this interlock is the one most frequently ignored, and as Mr. Ferguson points out it is in many ways the most important. In connection with potential transformers he has rather misinterpreted my remarks. When I suggested that no potential transformer should be connected to the busbars without the intervention of an oil switch I did not intend that a special oil switch should be installed for

the busbar potential transformers. It is quite an easy matter to do away entirely with all potential transformers on the busbars and to carry out all the necessary synchronizing by means of potential transformers connected to each feeder and each generator. If this is done the incoming machine is synchronized, not with the busbars, but with one of the running machines which is already connected to the busbars. In the case of static sub-stations it is very seldom that potential transformers are really essential, and on the system shown in Fig. 8 they are probably only installed in 10 per cent of the cases. The step-down transformers themselves to a great extent fulfil the purposes of the potential transformer.

Professor Marchant asks for further particulars with regard to the note on page 127 about the voltage-drop on overhead lines with the split-conductor system of protection. The explanation is that the inductance of an overhead line, other factors remaining constant, does not vary inversely as the sectional area but as the logarithm of the reciprocal of the square root of the sectional area. Consequently if a circuit be divided into two parallel circuits each of half the sectional area the combined inductance is reduced. The amount of the reduction depends on so many factors that it is difficult to give specific figures. In particular it is affected by the mutual inductance of the two circuits, which will vary very much according to the arrangement of split conductors which is adopted.

I have calculated the ratio of the inductance of an ordinary circuit to that of the corresponding split-conductor circuit for two types of split-conductor construction, assuming in each case 0.15 sq. in. of copper per phase and a spacing of 4 ft. between phases. With the original arrangement of split conductors with equal spacing between splits to that between phases the ratio is about 1.75, but with the more recent construction, with the splits carried on the same insulators at about 4 in. spacing and with spreaders at intervals, the ratio is reduced to about 1.25. These ratios are only very slightly modified by alteration in the phase spacing or sectional area.

He also raised the question of the swaying of wires on long spans and mentioned that very little difficulty is usually experienced. While in Cardiff recently I had the pleasure of seeing on the South Wales Power Company's system a span just over a quarter of a mile long, and I was informed that no trouble had been experienced with it. At the same time I know of an important case where such trouble occurred. It was on a line with aluminium conductors, and seemed to be caused by winds making a slight angle with the direction of the line and not by winds at right angles to it. Professor Marchant's theoretical formulæ gave a most striking and satisfactory confirmation of the curves which I obtained from actual commercial conditions. I do not, however, quite follow his further remarks on the economical current density for a cable already laid. If the load is definitely fixed, of course the current density is fixed also. On the other hand, if it is necessary to deal with an increased load it will be a question of the density at which it will pay to increase the capacity by laying an additional cable, and in this case I should have thought the fact that one cable was already laid would not have modified the way in which the problem had to be treated.

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Mr. Harlow, and subsequently Mr. Ratcliff and Mr. Palmer, have confirmed and elaborated the brief reference which I made to the design of high-pressure current transformers, and I am particularly glad that Mr. Harlow gave some actual figures showing the temperature rises which may be expected. Although this matter is fully appreciated by a few engineers who have come in contact with such troubles on large systems, I am sure it is not realized by most of those engineers whose systems are at present in the early stages of growth. In reply to Mr. Ratcliff I may say that I have personally experienced more than one current-transformer failure which could be traced to this cause. I agree with him, however, that trouble due to short-circuiting of the primary turns by high-frequency discharges is an equally important point, and it is very desirable in all cases where it is in any way practicable to adhere to single-turn bar-type current transformers. When a strong point is made of this it is surprising in how few cases it is really essential to depart from this construction, and even in such special cases not more than four turns are usually necessary. A further point which is not mentioned is the secondary insulation on current transformers. This is frequently treated as of no importance, but under very heavy short-circuits the iron circuits of most current transformers become saturated and the secondary voltage wave may be very peaked with quite a high maximum value. In the case of certain protective current transformers which are run under conditions approximating to an open-circuited secondary, this matter is of particular importance.

Mr. J. B. Palmer raised an important point affecting instrument manufacturers when he pointed out that the design of current transformers is much assisted by the development of instruments which have low volt-ampere characteristics.

Mr. Harlow refers to the fact that no actual figures have been given for the opening speed of oil switches. At one time anything above 5 feet per second was the exception, but 10 feet per second is now quite a usual figure and in some cases as high a figure as 20 feet per second has been reached. I do not think it possible to state an ideal figure, as the higher it can be taken the more satisfactory should be the operation of the switch unless the high speed is obtained in such a way as to weaken the switch in other directions. I was somewhat surprised that Mr. Harlow should advocate feeder reactances, but I assume his remarks only referred to certain special instances. Their disadvantages have already been fully put forward in discussions on papers before the Institution,\* but briefly put they have the two great disadvantages that they do not protect a switch in the case of a breakdown on the reactance or on the leads from the switch to it, and that they increase the voltage drop and thereby very appreciably reduce the permissible area of distribution at a given voltage. Of course, as pointed out in the discussions referred to, this is only true of the general case, and I agree there may be isolated instances in which their use may be desirable. I was asked to give some figures as to the mileage of split-conductor mains in use on the system shown in Fig. 8. The total mileage of high-pressure mains on this system is just over 700, and of this some 140 miles are protected on the split-conductor system and

some 380 miles on the Merz-Price system, the balance representing cables installed before the development of the balanced protective gear, both on the main system and on systems since linked with it. This balance only represents perhaps half of the original networks, since a large proportion of these old mains have been converted to automatic protection either by the subsequent laying of pilots or by grouping in pairs to form split-conductor mains. No doubt as the system develops further these remaining overload-protected mains will be changed over and incorporated properly into the system.

In reply to Mr. Harlow's further question the use of split switches has been the standard practice now for some two years, but a large amount of the original reactance-type split-conductor gear had been previously installed and has worked in a perfectly satisfactory manner. There is no reason why it should not be used except that the current transformers are somewhat expensive and cumbersome and have to be wound with a considerable number of turns, whereas the split-switch system allows of the use of bar-type current transformers.

I cannot quite follow Mr. Richards' difficulty about the load factor of the network. Assuming, as I did, a sub-station load factor of 30 per cent and a corresponding power-station load factor of 50 per cent, both these figures being actually obtained in practice, it must necessarily follow that the average load factor of the cables is between these limits. In a simple radial system it will of course be the same as the sub-station load factor, but the more the system is interconnected the more it will tend to approach the power-station load factor. Also on an interconnected system the nearer the cable is to the power station the larger the number of sub-stations which draw a portion of their supply through it, and consequently the higher its load factor. It would be rather a hopeless task actually to work out the exact figure on a system of any size, but I do not think my assumption of 40 per cent can be far out. In the case of the North-East Coast system the power-station load factor is higher than 50 per cent and I am quite sure the feeder load factor is above 40 per cent.

In my reply to Professor Marchant I have already dealt with the decreased inductance of split-conductor mains.

The problem of the automatic regulation of the secondary voltage on step-down transformers, which is referred to by Mr. Watson, is not one which I have found to arise frequently in practice. This is probably because, as a general rule, the consumer can put up with a reasonable amount of voltage variation at his supply terminals owing to the fact that his distribution circuits are short and do not produce heavy voltage-drops. On a system with considerable diversity the voltage variation is also considerably less than the actual voltage-drop between the power station and the particular sub-station. The problem is chiefly of importance in the case of step-down sub-stations supplying a lighting network, and I know of several instances where this difficulty has been quite satisfactorily overcome by the use of small low-pressure induction regulators automatically controlled by a voltage regulator. The original form of feeder protection on the North-East Coast was the usual combination of overload and reverse-power relays, and in the endeavours

\* *Journal I.E.E.*, vol. 52, pp. 521 and 584, 1914.

to obtain satisfactory operation by this method practically every form of relay developed both here and on the Continent was tried without much success. Of course it is now some 10 years since the balanced-current system of protection was introduced, so that those original troubles are now rather ancient history. In the case of the star-shaped distribution area which Mr. Watson thinks would offer a difficult problem for the interconnected system, I think it would be found that it could be easily dealt with by some combination of the typical systems (e) and (g) in Fig. 9, and that this would give a much more economical arrangement than a combination of the corresponding arrangements (f) and (h) in the same figure.

Mr. Watson, like one or two other speakers, is, I think, inclined to look upon the North-East Coast system as the product of special local conditions and therefore as an isolated instance which is not likely to be repeated in other parts of the country. I cannot agree with this at all. To my mind it corresponds very closely to a co-operative linking up of the Lancashire undertakings, and just as the Newcastle-upon-Tyne Electric Supply Company and the Cleveland and Durham Electric Power, Ltd., although entirely distinct Companies, operate their systems in parallel for their mutual benefit so as to run under the most economical conditions, so I should imagine that in the future many of the existing Lancashire systems will be part of one large network covering the whole county, each system retaining its local independence. If this were done a system would be established which would more than rival the North-East Coast system. Already, in the Manchester area, I think the density of load and the number of sub-stations per square mile is probably greater than that in any part of the North-East Coast.

I cannot agree with Mr. Fernie that cables can be rendered immune from external damage, although with proper precautions the risk is very slight. Colliery subsidence may occur in most unexpected places, railway embankments may slip, trains be derailed in tunnels, and even the supply authority may be mistaken as to the routes of the cable. In fact I know of several cases in which cables have been damaged on the supply authority's own property. The proper factor of safety on cables is difficult to specify, but I think it is generally admitted that it can be less the higher the voltage, as the surge pressures do not increase at a proportionate rate. The class of work I have allowed for corresponds to the best practice of the day, and the factors of safety on the cables are about those mentioned. Some 11,000-volt cable in the Newcastle district is at present being run at 20,000 volts for experimental purposes, but it is too soon yet to make any definite deductions. In such a case the 20,000-volt line for underground cable in Fig. 7 would coincide with the 11,000-volt line. I am glad that Mr. Fernie has mentioned the steeper slope of the 20,000-volt cable line in Fig. 7, as it may indicate to cable makers a direction in which a useful advance can be made. It is due to the rapid increase in the cost of 20,000-volt cable as the section increases. This is clearly illustrated in Fig. 1, and it shows the great importance of grading the insulation thickness on high-voltage cable according to the section. In Fig. 1 a small amount of grading has been allowed for, but not nearly as much as is probably justifiable.

Mr. Morton rightly points out that the cost of trenching and wayleaves are usually independent of the section of the main, but I cannot agree with him that they are only of importance in comparing cables with overhead lines. Both these items enter directly into the consideration of the lay-out of the system and the most economical voltage, as different lay-outs or different voltages may mean widely different total lengths of main, with correspondingly different costs for trenching and wayleaves. The fact that the economical current densities work out so close to "1,000 amperes per square inch" was also rather a surprise to me, since when it was realized that high-pressure paper cables could be safely run at much higher densities most of us came to regard the old rule as an antiquated "rule of thumb." My allowance of  $7\frac{1}{2}$  per cent as the maximum working voltage-drop in the mains is, perhaps, rather conservative, but quite apart from the further drop in transformation there is always some drop in the consumers' low-pressure circuits. It must also be remembered that the statutory limits of voltage variation are fairly stringent. Mr. Morton states that he would feel safe in allowing a 10 per cent drop in the mains for any load factor up to 50 per cent. I do not think he means us to infer that he would allow a lower drop at a higher load factor, but it may be as well to point out here that the exact contrary is the case on a high-pressure system, as the higher the load factor the less the variation in the load, and hence in the drop. It is voltage variation at the consumers' terminals which is really the important factor, as a steady drop can easily be taken care of by tappings on the transformers.

Mr. Morton raises the question of step-up transformers, which I have already dealt with in reply to Mr. Welbourn. Most engineers will not, however, agree with him in proposing direct generation at 10,000 or 11,000 volts. Of course it can be, and is, done, but it gives an unsatisfactory stator winding, and the tendency of modern opinion, both in this country and in America, is towards installing step-up transformers for all pressures above 6,000 volts. It is, of course, a question of balancing the extra cost of the transformers against the value of the additional security. The very favourable case which Mr. Morton was able to make for 50,000-volt transmission is full of promise for the future, and it seems as if the bending over of the curves in Figs. 11 and 13 will not be as much as I thought at higher voltages. The chief reason for this bending over is that which I referred to in my reply to Mr. Fernie in connection with the inclination of the 20,000-volt line in Fig. 7.

Mr. Rosenbaum refers to the use of earthing switches in place of isolating switches on split-conductor feeders. This was originally done, as he suggests, to minimize the number of variable resistance contacts, but it has been found in practice that from this point of view it is an unnecessary refinement. The use of an earthing switch has, however, several advantages and I think only one disadvantage. The disadvantage is that if the oil switch at one end of a feeder requires adjustment it is necessary to open the switch at the far end. The advantages are a simplified interlocking scheme and a reduction in the number of isolating switches, which are always a potential source of trouble. Where there is regular attendance at the switching centres, the disadvantage is negligible and the plain earthing switch is preferable, not only for split-

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conductor feeders but for all apparatus. In the case of static sub-stations where there is no attendance, the disadvantage is more serious and it is probably better to install 3-position isolating switches with earthing contacts. If this is done the interlocking is so arranged that access can only be obtained to the feeder end when the isolating switch is fully open and in the earthed position, but access can be obtained to the oil switch when the isolating switch is in the mid-position, *i.e.* open but not earthed. The special design of switch referred to by Mr. Rosenbaum, in which the pressure of the gases is used to increase the speed of break, is one of which more will be heard in the future and it is at present receiving serious attention in this country, but I do not think any data as to its behaviour under actual short-circuit conditions are available. I am asked to give figures for the cost of balanced-current and split-conductor protection. For the former the figure of 2s. per yard which I have taken in my

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calculations is approximately correct for both cables and overhead lines and is independent of the section and voltage. In the case of split-conductor work the extra price is not more than this, but the exact figure varies with both section and voltage. For cables the additional cost of the cable laid complete is about  $11\frac{1}{2}$  per cent at 6,000 volts, and  $6\frac{1}{2}$  per cent at 20,000 volts. For overhead lines it may be taken as varying from 12 per cent on the smaller sections up to 8 per cent on the larger sections.

In my reply to Mr. Partridge\* I have already dealt with Mr. Ratcliff's criticism that I have not considered voltages higher than 20,000. The limitation is not due to any anticipated difficulties in the operation of systems at higher voltages. I quite agree with him that it is current rather than pressure which is the difficulty in switchgear design, but it must not be overlooked that short-circuit currents are likely to increase with the voltage.

\* Page 236.

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## THE PREDETERMINATION OF THE PERFORMANCE OF DYNAMO-ELECTRIC MACHINERY.

By Professor MILES WALKER, Member.

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### SUMMARY.

This paper opens a discussion on general methods of calculating dynamo-electric machines and gives an outline of a method which is applicable to all types of such machines, whether alternating-current or continuous-current generators or motors, or rotary converters. Simple rules are given for determining the various quantities upon which the performance of a machine depends; in particular, the method of arriving at a temperature rise which may be expected is more completely developed than in a previous paper \* by H. D. Symons and the author.

Almost every electrical designer has his own particular method of calculating a machine and arriving roughly at its performance. Some of these methods are exceedingly short, the figures covering not more than a sheet of note-paper; others are exceedingly elaborate, occupying some 10 or 15 sheets of foolscap. One designer is generally interested in the method of another, and, in turn, is eager to support the particular method which he himself adopts. It may therefore be of interest for the Institution to have a discussion upon general methods of design, so that everyone may have an opportunity of showing the virtues of his own pet procedure.

Our ability to foretell the performance of an electrical machine, whether it be an alternating-current or continuous-current generator or motor, or a rotary converter, depends in the main upon our ability to calculate:

- (1) The magnetizing current;
  - (2) The armature reaction;
  - (3) The losses in copper and iron;
  - (4) The temperature rise;
- and, in the case of commutating machines,
- (5) The commutating conditions.

The last of these headings requires a paper to itself, so that this paper will only deal with the first four.

\* H. D. SYMONS and M. WALKER: "The Heat Paths in Electrical Machinery," *Journal I.E.E.*, vol. 48, p. 674, 1912.

Whatever the machine may be—alternating-current or continuous-current generator, induction motor, or rotary converter—the methods of calculating these quantities are in the main the same. It is therefore possible to have one general method of calculation for all these machines; and if such a general method could be established it would greatly simplify the work of the student of design.

If we examine the methods of design described in textbooks and in articles published in the technical journals, we shall see that they can be broadly divided into two classes:

- (1) Those which take as the basis of the design the total flux per pole; and
- (2) Those which take as the basis the maximum flux density in the air-gap.

In many cases where the total flux per pole is taken as the starting-point, the calculation proceeds on lines somewhat similar to those employed in the calculation of transformers. For instance, in calculating the electromotive force generated in the armature, one writes

$$E_c = K_t f S \Phi \times 10^{-8} \quad \dots \dots (1)$$

where  $f$  is the frequency,  $S$  the number of turns,  $\Phi$  the flux per pole, and  $K_t$  a coefficient depending upon the field-form and coil breadth.

On the other hand, where the flux density in the air-gap is the initial quantity kept in view, the formula for the voltage generated in a single conductor takes the form

$$e_c = v B l \times 10^{-8} \quad \dots \dots (2)$$

where  $v$  is the velocity in centimetres per second,  $B$  the flux density in the air-gap, and  $l$  the length of iron in centimetres.

The first method has the advantage that, after fixing  $K_t$ , it only deals with the total flux, without troubling about the distribution of the lines of force in the air-gap; but this very feature limits its application to those cases where

we are content to know the mean electromotive force generated. The first formula is therefore not so generally applicable as the second one, which gives us a more complete visualization of what is happening under each pole.

It is possible to have a combination of these methods which preserves the advantages of both. Suppose we have a rotor surrounded by the stator, as in an induction motor, but that the flux in the gap, instead of changing from point to point along the periphery, is of one sign and distributed uniformly, just as it is in a homopolar machine. If  $B$  is the flux density in the air-gap,  $r$  the radius of the rotor in centimetres, and  $R_p$ , the speed in revolutions per second, then the total flux passing into the rotor will be

$$B \times 2 \pi r l,$$

and the total flux cut per second

$$B \times 2 \pi r / R_p.$$

Writing  $A_p$  for the total working surface of the armature (the area of the gap space)  $= 2 \pi r l$ , we have the electromotive force  $e_p$  generated in one conductor:

$$e_p = A_p B R_p \times 10^{-8} \quad (3)$$

or

$$e_p = A_p B R_{p,m} \times (1.66) \times 10^{-8} \quad (4)$$

The expression  $A_p B$  gives us the magnetic loading of the frame.

If now, instead of a uniform air-gap and a constant flux density we have salient poles and a flux density varying from point to point along the gap, the formula for the average electromotive force generated in the conductor becomes

$$e_p = K_f \times A_p B \times R_{p,m} \times (1.66) \times 10^{-8} \quad (5)$$

where  $K_f$  is a coefficient depending on the ratio of the pole-arc to the pole-pitch. This coefficient,  $K_f$ , is in fact equal to the ratio of the area of the curve representing the field-form to the area of the rectangular field-form which we should have if the pole-arc were equal to the pole-pitch and the air-gap were perfectly uniform. Where a number of conductors  $Z_s$  are connected in series, as in the armature of a continuous-current generator, the formula for the total electromotive force generated becomes

$$E_s = K_f \times A_p B \times Z_s \times R_{p,m} \times (1.66) \times 10^{-8} \quad (6)$$

Here  $A_p B$  is the ideal magnetic loading of the frame; that is to say, the magnetic loading which we could have if the pole-arc were equal to the pole-pitch. The coefficient  $K_f$  informs us what fraction of this ideal magnetic loading we have in the machine in question.

In the case of an alternating-current generator, the formula for the electromotive force can still take the same form as (6), but we must introduce a new coefficient,  $K_m$ , to take into account not only the area and shape of the field-form, but also the width of the phase band of armature conductors, the taking of the square root of mean square value of the voltage, and the ratio of the number of conductors in series per phase to the total number,  $Z_{a,s}$ , of the conductors on the armature. Thus, for an alternating-current generator or motor we have

$$E_s = K_f \times K_m \times R_{p,m} \times Z_s \times A_p B \times (1.66) \times 10^{-8} \quad (7)$$

By the use of a suitable coefficient,  $K_m$ , this formula can be used for the electromotive force generated in any dynamo-

electric machine; and for general use it has the following advantages in its favour:—

(1) The formula contains the term  $B$ , representing the maximum value of the flux density in the air-gap, and for many reasons it is well to have this quantity continually before us.

(2) The expression  $A_p B$ , the maximum flux density multiplied by the total area of the active surface of the armature, has a fairly definite maximum value for a given frame or carcass; so that if we are familiar with our frame we know by a glance at our calculation to what extent we are making good use of the material. For instance, if we have an armature of an alternating-current generator having a diameter of 150 cm. and a length of 30 cm., then  $A_p = \pi \times 150 \times 30 = 14,160$ ; and if we know from experience that  $B$  in the air-gap cannot be made higher than 10,000 C.G.S. lines per sq. cm., the maximum value of  $A_p B$  for that frame would be  $1.4 \times 10^8$ .

As this quantity,  $A_p B$ , is almost independent of the number of poles, the designer soon comes to know the value it should have for any particular frame, and is able to judge at a glance how far he is utilizing the magnetic circuit.

(3) The maximum flux density in the teeth can be found by dividing  $A_p B$  by the total section of all the teeth (see page 258). This is a shorter and more convenient method than that employed where the total flux per pole is taken as the basis of calculation. In the latter case it is necessary to make an estimate of the virtual number of teeth per pole, and this is not a simple matter when the pole is bevelled.

(4) The coefficient  $K_f$  has a certain recognized maximum value for a certain kind of machine. Thus, for a 3-phase generator,  $K_f$  may be equal to 0.4. If it has a lower value in any calculation under consideration (as may be the case where the pole-arc is a small fraction of the pole-pitch), the designer's attention is called to that circumstance.

(5) If we multiply both sides of Equation (7) by  $I_{a,s}$ , the current in the armature conductors, we get a formula for the output, containing the two expressions:

$A_p B$ , the magnetic loading; and

$I_{a,s}$ , the current loading.

Both these quantities being clearly before us during our consideration of alternative designs, we can observe how one decreases and the other increases in the fight for room which occurs between iron and copper.

Any general method of design should in its nuclear form be exceedingly short, and capable of reaching rough results in the course of a few minutes. At the same time it should be capable of developments which lead to more accurate results at any stage of the calculation. Moreover, a general system of calculation should be founded upon sound principles and not merely built upon empirical rules. A method of calculation which, though rough, is based on arguments that must be right from the very nature of things, helps the designer in the habit of forming rapid mental estimates; whereas an empirical rule, however often it may be applied, never gives its user the faculty of rapidly estimating with approximate accuracy, because it does not take into account all the factors that determine the result. A busy designer would never get through his work if he stopped to calculate everything.

He guesses a great deal, or makes rapid mental estimates of quantities; he has not time to calculate. He is never justified in so guessing unless he knows with fair accuracy the limits of his possible error, and knows that with that error he would still have a machine which will comply with its specification. This faculty of guessing, when properly carried out, is really a process of rapid mental calculation based upon many machines calculated and tested in the past.

The author proposes to give a general method of design applicable to all the classes of machines, and to illustrate it by applying it to a 3-phase turbo-generator and an induction motor. As some of the methods of calculating the quantities set out on page 246 are already well known, it would be tedious to go into the explanations of these in the body of the paper; the author therefore proposes to describe each method of calculation in appendixes, so that any student who is not familiar with the methods can find them there. In Appendix I is described a method of plotting the field-form of a turbo-generator having highly saturated teeth. A method of calculating the coefficient  $K_v$  is given in Appendix II.

In most designing offices, calculation sheets are provided. The figures relating to each dimension of the machine and each important quantity are given a definite place on the sheet, so that they can be readily referred to. The process of calculating, then, merely consists in filling in the proper figures in the appropriate places, and this is done in a certain order, the slide-rule or a short calculation being used to step from one quantity to the next.

It is usual to have one kind of calculation sheet for a continuous-current generator, another for an induction motor, and another for an alternating-current generator, and so forth. If, however, one system of calculation is employed for all machines, one printed form can be employed for all; and there is a distinct advantage in this, because an improvement in method or an increase of rating can thereby be more readily extended from one class of machine to another.

On page 250 is given a calculation form applicable to any type of dynamo-electric machine. It is arranged upon the following plan: The first three lines above the heavy ruling give the performance of the machine—output, power factor, phases, volts, amperes, cycles, speed, temperature rise, regulation, etc. The next line gives the customer's name and numbers relating to the office record. The next two lines give the most important constants relating to the frame—the frame number, the circumference, the gap area or area of working face  $A_p$ , the magnetic loading  $A_v B$ , the current loading  $I_a Z_a$ , the current loading per centimetre of periphery, and the output coefficient. The next line gives the voltage constant  $K_v$ , and also the voltage formula. Below this, in the middle of the form, are given skeleton sketches in which the important dimensions of the slots, teeth, poles, etc., can be readily filled in. On the left-hand side are found the chief data relating to the armature, which may be revolving or stationary; and on the right-hand side are the chief data relating to the field-magnet, which may be either stationary or rotating. Below these are given the figures from which the magnetization curve is plotted, and particulars of the commutator, if any. Below this, again, are given the figures for the efficiency, and in the case of

induction motors the important constants upon which the short-circuit current of the machine depends.

#### CALCULATION OF THE PERFORMANCE OF A 3-PHASE TURBO-GENERATOR FROM THE DIMENSIONS OF THE MACHINE.

The machine chosen is a 2,700-k.v.a., 6,600-volt, 3-phase, 50-cycle generator to be driven by a steam turbine at 3,000 r.p.m. The calculation sheet is given on page 250. The power factor of the load is 0.8; the amperes per terminal 236; the amperes per conductor 236; the permissible temperature rise 45 degrees C. (by thermometer).

It is not usual with these high-speed 2-pole generators to give any guarantee of regulation. The voltage is usually controlled by an automatic regulator. It is not within the province of this paper to give the considerations which fix the dimensions of the machine; the dimensions are supposed to be given, and the problem is to calculate the performance.

The external diameter of the stator stampings is 122 cm.; the bore is 63.5 cm., and the gross length of iron 115 cm. The circumference of the working face is 192 cm., and the area 22,100 sq. cm. There are 21 radial air-vents in the stator, each 0.95 cm. wide, giving a net length of iron and paper of 95 cm., and a net length of iron in the armature of 84.5 cm. The depth below slots is 25 cm. The cross-section of the stator iron is 2,120 sq. cm., and the volume 645,000 cubic cm. There are 36 slots, of the dimensions given in the sketch, page 250, each containing six conductors measuring 0.4 x 1.7 cm., giving a current density of 364 amperes per sq. cm. The voltage coefficient (see Appendix II) is 0.392. There are 216 conductors in all the phases. The voltage formula reads as follows:—

$$6,600 = 0.392 \times 50 \times 216 \times A_v B \times 10^{-8} \\ A_v B = 1.56 \times 10^8$$

The total cross-section of all the stator teeth (see Appendix I) = 10,600 sq. cm., so that the density in the stator teeth

$$= 1.56 \times 10^8 / 10,600 = 14,700 \text{ C.G.S. lines per sq. cm.}$$

From our iron-loss curve (page 263) the loss is 0.1 watt per cubic cm., giving 4,400 watts in 44,000 cubic cm. The field-form constant,  $K_f$ , amounts to 0.625 (see Appendix I), so that the working flux per pole is

$$1.56 \times 10^8 \times \frac{0.625}{2} = 4.85 \times 10^7.$$

As the cross-section of the stator iron is 2,120 sq. cm., we have the flux density behind the slots

$$= 4.85 \times 10^7 / (2 \times 2,120) = 11,400 \text{ lines per sq. cm.}$$

This gives a loss of 0.06 watt per cubic cm., or 39,000 watts in all, which, added to the loss in the teeth, gives a total of 43,400.

The resistance of all the armature conductors in series (see Appendix IV) amounts to 0.15 ohm, or 0.05 ohm per phase. The increase in the armature copper-loss owing to eddy currents in the copper, worked out by the method

given by Field,<sup>2</sup> amounts to 5 per cent. The total loss in a metre length of coil amounts to 105 watts. The cooling surface of a metre length of coil is 1,200 sq. cm., so that we have 0.088 watt per sq. cm. As the thickness of insulation is 0.27 cm., we have

$$\frac{0.088 \times 0.27}{0.0012} = 20 \text{ degrees C. difference of temperature between copper and iron.}$$

Returning now to the losses to be dissipated by the stator surface, we find that the total armature copper-loss amounts to 10,500 watts. Multiplying this by 115/265, we get 4,600 watts for the buried copper loss. The iron loss plus the buried copper loss thus amounts to 48,000 watts. To this we may add 10 per cent for end-plate and other undetermined losses, making in all 53,000 watts to be dissipated by the surfaces of the stator. We are allowed 45 degrees C. rise above the air, and we may therefore, on the basis of figures given on page 689, vol. 48 of the *Journal*, take 25 degrees as the mean temperature difference between the air and iron in the air-gap. The velocity of the rotor is 92 metres per second; so that we have

$$25 = \text{watts per sq. cm.} \times \frac{333}{1 + 0.1 \times 92}$$

i.e. watts per sq. cm. = 0.77.

Multiplying this by the area of the working face, 22,100, we get 17 kilowatts dissipated from the working face.

Next, as to the watts dissipated from the sides of the ventilating ducts, here  $h_v$  may be taken at 0.0007  $v$  (see Appendix VI). With an air supply of 4 cubic metres per second, the mean velocity,  $v$ , in the ducts may be taken at 8 metres per second.<sup>†</sup> This gives  $h_v = 0.0056$ . The mean difference of temperature between the air and the walls of the ducts may be taken as 13 degrees C. for a temperature rise of the iron of 45 degrees C.<sup>‡</sup> Thus the watts per sq. cm. will be

$$13 \times 0.0056 = 0.067.$$

The total area of all the ducts is 450,000 sq. cm., which can get rid of a total of 33,000 watts.

The watts dissipated from the outside surface (see Appendix VI) may be taken at 0.15  $\times$  43,000 = 6,500, giving a total of 56,500 watts; so that the temperature rise will be within 45 degrees C.

The method of working out the magnetization curve will be well understood from the figures given in the form on page 250. At 6,600 volts no load we require about 14,100 ampere-turns per pole.

In calculating the flux which passes through the polar projection lying between the slots, allowance must be made for the leakage flux across the slots (see page 259) and the leakage flux to the end-bells (see Appendix I). At no load this leakage is not so great as at full load when the armature is yielding counter ampere-turns. It is therefore desirable to plot two magnetization curves, one, the true no-load magnetization curve shown by the full line in Fig. 6, and a second, showing the increased ampere-turns necessitated by the increased leakage, indicated by the dotted line in Fig. 6. The figures for plotting these curves

are given on page 250. At no load 6,600 volts the ampere-turns on the polar projection are only 112; but with the increased leakage at full load they amount to 350. At 7,500 volts the increase is from 300 to 1,000 ampere-turns. This dotted curve in Fig. 6 is employed when calculating the ampere-turns at full load. These ampere-turns as worked out according to the method given in Appendix I amount to 24,600. To allow a margin we should design the winding to carry 29,000 ampere-turns.

As the part of the winding which projects from the slots is rather difficult to cool it is sometimes made of greater cross-section than the part lying in the slots. In this case the field coils are made of copper strap measuring 0.305 cm. thick by 1.9 cm. wide. The part which is to lie in the slot is then milled down to 1.52 cm. wide. There are 720 metres of the smaller section and 372 metres of the larger. The resistance of the whole is 0.395 ohm, cold, or say 0.475 ohm, hot. The thickness of the wall of insulation in the slots is about 0.15 cm., and as the loss per square centimetre is about 0.18 we would expect to get

$$\frac{0.18 \times 0.15}{0.0012} = 22.5 \text{ degrees C. difference of temperature between copper and iron.}$$

This shows that the cooling conditions in the slots are so good that a large quantity of heat generated in the end-connections will be conducted along the copper into the slots. The method of arriving at the amount of heat so conducted has been dealt with in a previous paper.<sup>\*</sup>

The method of calculating the efficiency will be sufficiently well understood from the figures give on page 250.

#### CALCULATION OF THE PERFORMANCE OF AN INDUCTION MOTOR FROM THE DIMENSIONS OF THE MACHINE.

It is not within the province of this paper to go into the considerations which lead to the fixing of the dimensions of the various parts of induction motors. We must assume that the dimensions are given to us, and that it is required to calculate as nearly as possible the quantities set out on page 251. We have chosen a 600-h.p., 10-pole motor, to work on a 3-phase circuit at 2,500 volts and 50 cycles. The synchronous speed will therefore be 600 r.p.m. The outside diameter of the rotor stampings is 127 cm.; inside diameter 100 cm.; gross length 46 cm. There are 7 air ducts in both the stator and rotor, each duct 0.8 cm. wide. The net length of iron and paper is 39.4 cm.; taking 89 per cent of this, we arrive at a net length of iron of 35 cm. The depth of iron below the slots is 9 cm. The cross-section of iron behind the slots is 315 sq. cm., and the volume is 117,000 cubic cm.

There are 120 slots in the stator, each containing 6 conductors, 0.36 sq. cm. in area. These conductors form coils lying in slots 1 and 16, 2 and 15, 3 and 14, and 13, so that they form a normal full-pitch concentric winding. The total number of conductors in all phases is 720.

The first step in the calculation is to arrive at the total magnetic loading,  $A_2 B$ ; this is obtained from the formula

$$\text{Volts} = K_v \{ 1 \times R_{\phi} \times \text{No. of conductors} \times A_2 B \times 10^{-8},$$

$$\text{or } 2,450 = 0.41 \times 10 \times 720 \times A_2 B \times 10^{-8},$$

<sup>\*</sup> *Journal I.E.E.*, vol. 48, p. 684, 1912.

<sup>†</sup> For voltage coefficient  $K_v$ , see p. 257.

<sup>\*</sup> A. B. FIELD: "Eddy Currents in Large Slot-wound Conductors," *Transactions of the American Institute of Electrical Engineers*, vol. 24, p. 791, 1905. See also M. B. FIELD: "Eddy Currents in Solid and Laminated Masses," *Journal I.E.E.*, vol. 33, p. 1125, 1904.

<sup>†</sup> *Journal I.E.E.*, vol. 48, p. 712, 1912.

<sup>‡</sup> *Ibid.*, p. 713.

From this we find that  $A_c B = 0.83 \times 10^6$ . We have taken the voltage at 2,450 instead of 2,500, allowing 2 per cent drop in the stator winding.

To get the circumference of the working face we multiply the diameter, 100 cm., by  $\pi$ . This gives 314 cm. The working face is obtained by multiplying this figure by 46 cm.; this gives  $A_c = 14,400$  sq. cm. These figures are filled in on the fifth line of the sheet. If we divide  $A_c B$  by 14,400 we get the maximum flux density in the gap. The maximum density in the teeth is obtained by dividing  $A_c B$  by the cross-section of all the teeth. The method of calculating the cross-section of all the teeth will be easily understood from Appendix III. The figures are given on the calculation sheet under the side-heading "Teeth." The cross-section of the teeth in this case is 4,880 sq. cm.; dividing  $A_c B$  by this, we get a flux density of 17,000 lines per sq. cm.

The iron loss in the teeth, taken from the iron-loss curve (Fig. 11), comes to 0.13 watt per cubic cm.; the total volume of the teeth is 20,500 cubic cm., so that the loss amounts to 2,660 watts. To arrive at the flux per pole, we divide  $A_c B$  by the number of poles and multiply by the field-form constant  $K_f = 0.66$ . Thus,

$$0.83 \times 10^6 \times 0.66 / 10 = 5.5 \times 10^5 \text{ lines per pole.}$$

To arrive at the flux density in the iron behind the stator slots, we have

$$\frac{5.5 \times 10^5}{2 \times 315 \text{ sq. cm.}} = 8,750 \text{ lines per sq. cm.}$$

This will cause a loss of 0.045 watt per cubic cm., or 5,200 watts in the 117,000 cubic cm., so that the total iron loss in the stator amounts to 5,200 + 2,660 = 7,860 watts.

To this figure should be added the loss occurring in the copper in the slots, so we proceed to calculate the copper loss. This is done most conveniently by the method given in Appendix VI. The size of the conductors is  $0.37 \times 1$  cm., giving 0.36 sq. cm. if allowance is made for rounded corners. The amperes per square centimetre are 354. The length of the conductor in the slot is 47 cm., and the length outside 75 cm., giving a total length per conductor of 111 cm. Multiplying by 720 conductors, we get 800 metres. The resistance per 1,000 metres is 0.474 ohm, giving a total resistance of all conductors of 0.38 ohm, or 0.127 ohm per phase. The watts per metre length of coil are 56, and the total surface of coils per metre 1,040, giving 0.054 watt per sq. cm. In order to find out whether the heat conductivity of the insulating tube is sufficient to allow the heat to pass to the stator iron without an excessive rise of temperature of the copper, we adopt the method described in Appendix VI. The figures are

$$0.054 \times 0.26 / 0.0012 = 11.7 \text{ degrees C. difference of temperature between copper and iron.}$$

If the temperature of the iron were to rise 40 degrees C. above that of the atmosphere, the copper would only be about 52 degrees C. above the atmosphere. Multiplying the total resistance, 0.38, by the square of the stator current, 127 amperes, we get the stator copper-loss; and allowing for the rise in resistance of the copper we get the armature I<sup>2</sup>R loss as 7,400 watts. Multiplying this by the ratio 46 : 111, we get the buried copper loss as 3,100 (entered

on the sheet under the side-heading "Core"). This, added to the total iron loss, gives us 10,960 watts to be dissipated by the surfaces of the stator. The method of calculating the watts dissipated from the gap area, the vent area, and the outside area, is given in Appendix VI; and the figures are given in the calculation sheet, page 251. We see that for 40 degrees C. temperature rise of the stator we can expect to get rid of 14,320 watts; so that if the total loss to be dissipated is 10,960 watts, the temperature rise of the iron may be expected to be not more than 30 degrees C.

The figures for the magnetization curve are given in the calculation sheet and require no explanation. As 2,450 volts are generated by the revolving flux, the maximum magnetizing ampere-turns amount to 1,460. From Appendix II we find the magnetizing current from the formula:

$$0.43 \times I_m \times Z_s = 1,460; \text{ so that } I_m = 46.5.$$

No. of poles

\* The friction and windage losses of induction motors are generally found from the curves which have been plotted from tests of similar machines; in this case they amount to 7,500 watts. Adding this to the iron loss and copper loss at no load, we get 16,000 watts; so that the component of the no-load current in phase with the voltage will amount to 16,000 / (173 × 2,500) = 3.7 amperes.

The flux density in the rotor teeth is found by the method described in Appendix III, and amounts to 14,900. The rotor winding consists of 2 bars per slot lying in 150 slots, with barrel-formed end-connectors. Each conductor measures 0.6 × 1.1 cm. The number of turns is therefore 150, and the mean length of turn 188 cm.; and with a total length of 282 metres the resistance per phase is 0.025 ohm (cold), say 0.029 (hot). The value of the current in the rotor can be found from the circle diagram which is constructed from the data given in Appendices III and IV. The power factor of the rotor circuit at full load on a motor of this size and rating is generally of the order of 0.96. Instead of drawing the circle diagram we may, to get the rotor current approximately, make a guess at the power factor and proceed as follows:—

The output of the rotor is 448 kilowatts and the ratio of transformation is 2.4, so we have

$$\frac{448 \times 2.4}{2,500 \times 1.73 \times 0.96} = 257 \text{ amperes.}$$

The I<sup>2</sup>R loss in the rotor will be

$$257 \times 257 \times 0.029 \times 3 = 5,750 \text{ watts.}$$

The method of calculating the short-circuit current is given in Appendix III; and the figures will be found on the calculation sheet on page 251. The short-circuit current works out to 635 amperes. From the magnetizing current, no-load loss current, and short-circuit current, we can work out the circle diagram in the usual manner. This gives us the power factor at full load as 0.88; the starting torque, 0.36 times full-load torque; the maximum torque, 2.7 times full-load torque; and the maximum horsepower, 1,500 h.p. The slip at full load is found by taking the ratio of the rotor losses to the rotor input. The output of the rotor at full load is 448 kilowatts, so that the slip will be

$$\frac{5,750}{448 + 5,750} = 1.27 \text{ per cent.}$$





## APPENDIX I.

## PLOTING THE FIELD-FORM OF A CYLINDRICAL FIELD-MAGNET WITH HIGHLY SATURATED TAPER TEETH.

The process of plotting the field-form of a salient-pole machine in cases where it is unnecessary to take account of the saturation of the teeth is fairly simple, and is dealt with in the textbooks.<sup>3</sup> The methods of dealing with the field-form of a distributed winding, such as is found on a cylindrical field-magnet, have also been published.<sup>†</sup> In cases where the teeth of the field-magnet are tapered and highly saturated, the matter is somewhat more difficult, and it may be well to illustrate the process in the following example:—

The outer circle in Fig. 1 represents the inner diameter of the armature of the 2,700-k.v.a., 3-phase turbo-generator, particulars of which are given in the calculation sheet, page 250. A cross-section of the iron of the cylindrical field-magnet, which is 59 cm. in diameter, is shown in the figure. There are 32 slots spaced as if there were 42,

cross-section of the iron, plus the cross-section of the air, to the cross-section of the iron at any particular section under consideration.

The first step in the process of drawing the field-form is to plot an "air-gap and tooth-saturation" curve; indeed, where the slotting of the rotor is not uniform all round, it is necessary to have such a curve for each kind of slotting. Thus, one of these curves is required for the part of the rotor which is uniformly slotted, and another curve is required for the polar projection, which may be regarded as one large tooth. These curves are shown in Fig. 3 and are marked F and G.

In Table 1 are given the figures from which the "air-gap and tooth-saturation" curve for the slotted part of the rotor is plotted. In these curves it is well to take as abscissae ampere-turns per pole, and as ordinates the flux density in the air-gap on the middle line, shown in Fig. 1 by the dotted circle MM. The flux density on this line may be taken as the standard from which the flux density in an adjacent tooth may be calculated.

TABLE 1.  
*Calculation of Ampere-turns on Taper Teeth.*

	$l_2 = l_1$	Section of Teeth	Section of Iron and Air	K	$P_r$	$B_r = 5,000$				$P_r = 13,500$				$B_r = 6,500$			
						Apparent $B_r$	$H$ in B	Difference	Ampere-turns per cm.	Apparent $B_r$	$H$ in B	Difference	Ampere-turns per cm.	Apparent $B_r$	$H$ in B	Difference	Ampere-turns per cm.
C		10,000	21,300	2.29	2.21	11,100											
D	4.5	7,300	18,800	2.57	3.54	13,250	0.1		8	15,800	0.2		32	17,100	0.35		64
E	4.5	4,600	15,400	3.34	4.8	24,000	1.8	1.7	108	28,800	7.25	7.05	650	31,200	12.5	12.15	1,070
						Total			916	Total			3,063	Total			5,000

each polar projection occupying the space of five slots which are uncut. The gross axial length of the iron of the field-magnet is 115 cm.; there are 21 ventilating ducts each 0.95 cm. wide, leaving a net length of iron of 95 cm. There are 14 ventilating holes, 3.5 cm. diameter. The slots are 1.9 cm. wide and 9 cm. deep. This construction leaves the teeth very narrow at the base, only 1.17 cm. wide; and the teeth lying adjacent to the polar projections are so highly saturated that some care must be taken in calculating the drop in magnetic potential in them if the correct field-form is to be plotted. The method proposed by W. B. Hird<sup>‡</sup> for dealing with taper teeth may be employed with advantage. Curves plotted somewhat after the manner proposed by Mr. Hird are shown in Fig. 2. In order to allow for the magnetic flux which leaks along the slot and the ventilating duct, it is necessary to have a number of curves, each for a particular value of  $K_r$ , where  $K_r$  is the ratio between the

The first step is to find the relation between the flux density at this middle line and the ampere-turns expended on the air-gap. The length of the air-gap is 2.25 cm., and the air-gap coefficient<sup>§</sup> is 1.08; so that the ampere-turns on the gap are equal to  $B_r \times 2.25 \times 1.08 \times 0.706$ . Therefore for 7,000 lines per sq. cm. in the gap we have

ampere-turns per pole = 13,500.

This gives us the "air-gap line" shown dotted in the figure. For the part of the air-gap adjacent to the polar projections, where there are no slots in the rotor but only ventilating ducts, the air-gap coefficient is only 1.02. The air-gap line of this part would therefore be slightly above the thick dotted line in Fig. 3.

For the purpose of finding the ampere-turns expended on the teeth, we shall consider three sections of the teeth: one, C, taken on the surface of the rotor; another, D, half-way down the teeth; and another, E, at the root of the teeth. It will be found most convenient to make the calculation as if 42 teeth were cut on the rotor. Column 2 in Table 1 gives the length  $l_2 - l_1$  between C and D,

<sup>†</sup> HAWKINS and WALLIS, "The Dynamo."  
<sup>‡</sup> S. P. SMITH: "The Non-salient Pole Turbo-alternator and its Characteristics," *Journal I.E.E.*, vol. 47, p. 562, 1911.  
<sup>§</sup> W. B. HIRD: "The Reluctance of the Teeth in a Slotted Armature," *Journal I.E.E.*, vol. 29, p. 933, 1900.

<sup>\*</sup> HAWKINS and WALLIS, "The Dynamo."

4.5 cm., and between D and E, 4.5 cm. The third column gives the total cross-section of iron in all the teeth at the various sections. Column 4 gives the section of iron and air. From columns 3 and 4 we calculate the ratio  $K_r$  given in column 5.

The circumference of the middle air-gap line is  $61.25 \times \pi = 192$  cm. This multiplied by the gross axial length, 115 cm., gives us  $A_g = 22,100$  sq. cm. The apparent density in the teeth (that is, the density there would be if no flux leaked along the slots and vents) we will denote by  $B_t$ ; this is most conveniently found by multiplying the density in the gap by the ratio of the section of the gap to the section of the teeth, which is given in column 6 under the heading  $B_t/B_g$ . It is con-

$B_t$  at the section E, equal to  $1.8 \times 10^6$ . The difference,  $1.7 \times 10^6$ , divided by the difference between the values of  $B_g$ , gives 198 ampere-turns per centimetre. This multiplied by 4.5 gives 880 ampere-turns for the part of the tooth from D to E; so that the total ampere-turns on the tooth are about 916. This is set off from the thick dotted air-gap line in Fig. 3, and gives us a point on the "air-gap and tooth-saturation" curve. Similarly, for  $B_g = 6,000$ , the ampere-turns on the tooth amount to 3,080; and for  $B_g = 6,500$  the ampere-turns amount to about 5,090. Adding these figures to the ampere-turns on the air-gap, we get the "air-gap and tooth-saturation" curve shown by curve F in Fig. 3.

The saturation curve for the polar projection may be obtained in the same way, except that in this case it is

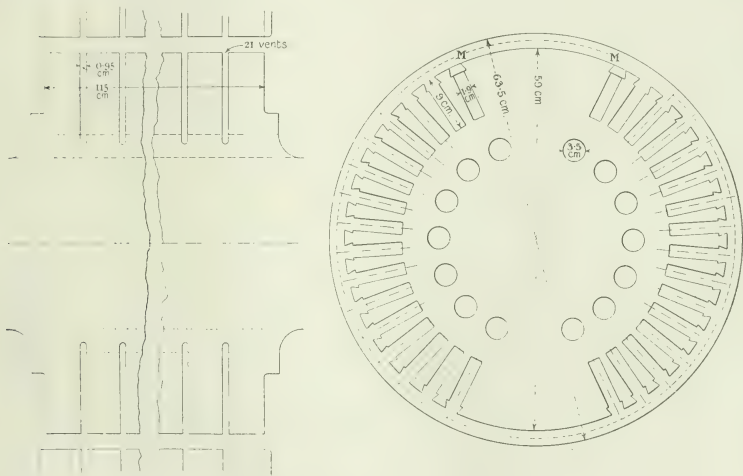


FIG. 1.—2,700-k.v.a., 3-phase Turbo-generator.

venient to make the calculation of the ampere-turns on the teeth for three densities in the gap; in this case,  $B_g = 5,000$ , 6,000, and 6,500. In the seventh column will be found  $B_t$  at the three sections for  $B_g = 5,000$ . It will be found that the ampere-turns on the part of the tooth lying between C and D are so small compared with the ampere-turns on the part from D to E that it is not worth while to apply Hird's method to the upper part of the tooth. It is sufficient to take the mean density, in this case 13,150, and find the ampere-turns per centimetre from the magnetization curve of the iron, in this case 8 ampere-turns per sq. cm., which multiplied by 4.5 gives about 36 ampere-turns on the part CD. To find the ampere-turns on the part DE, we find the value of  $\int H dB$  for the value of  $B_t$  at D, equal to about  $0.1 \times 10^6$ ; and the value of  $\int H dB$  for the value of

necessary to take into account the leakage flux, which may be estimated by any of the known methods.\* The magnetization curve for this part is shown by the curve G in Fig. 3.

The method of obtaining the field-form at no load, full voltage, is necessarily one of trial and error, because until we know the field-form we do not know accurately the value of  $K_r$ , and we cannot find  $K_r$  until we know the maximum ampere-turns on the poles. The usual practice is to guess the value of  $K_r$  from experience of previous machines, and from it to obtain an approximate value for the maximum flux density in the gap. In this case one or two trials give us a maximum density of 7,000 C.G.S. lines

\* R. G. JARVIS: "The Field Leakage of Turbo-alternators with Non-salient Poles," *Electrician*, vol. 75, p. 705, 1915.

per sq. cm. From curve G we find that this requires 13,700 ampere-turns per pole. We now lay out the spacing of the slots in the rotor on the abscissa line as in Fig. 4, and write down 13,700 ampere-turns per pole for

between slots 7 and 8, and gives the field-form a broader top, as shown by the outer curve. The exact shape of this curve cannot be calculated. Oscillograph records\* show that the field-form on a cylindrical magnet of this kind has

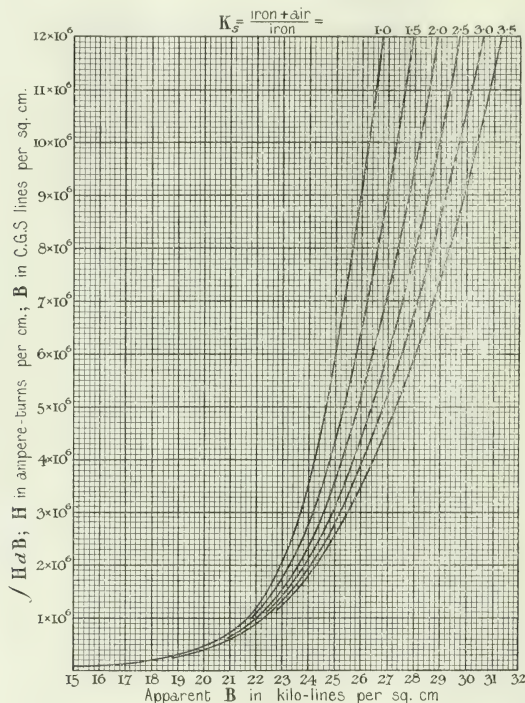


FIG. 2.

the part of the iron encircled by the conductors in slot 8, 12,000 for slot 7, 10,300 for slot 6, and so on.

Referring now to curve F, Fig. 3, we are able to plot the values of the gap density opposite to each tooth. It will be seen that Fig. 4 shows two curves; the inner dotted one gives the value of the flux density, 5,400, opposite to the tooth between slots 7 and 8, as obtained from Fig. 3. This would lead to a field-form which is too narrow across the top. In order to avoid this, a steel wedge is put in the eighth slot, which avoids the super-saturation of the tooth

appreciable steps on the sides; but the smooth curve shown in Fig. 4 is sufficiently near to the actual case for the purpose of finding  $K_s$ .

In order to calculate the total flux per pole it is convenient to use a coefficient which may be called the field-form coefficient, denoted by  $K_s$ , which gives the ratio between the area of the field-form and the area of the rectangle the

\* S. P. SMITH and R. S. H. BOULDING: "The Shape of the Pressure Wave in Electrical Machinery," *Journal I.E.E.*, vol. 53, p. 205, Fig. 9, 1915.

height of which is the maximum flux density in the gap and the base the pole-pitch. It is easily obtained in practice by running a planimeter around the curve in Fig. 4

form for a number of different excitations and find the voltage generated in each case. In practice, however, it will be found that with this type of field magnet the value

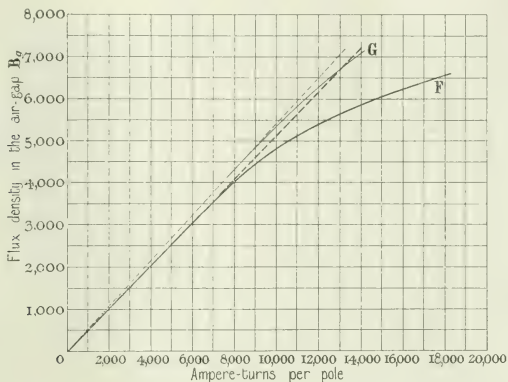


FIG. 3.

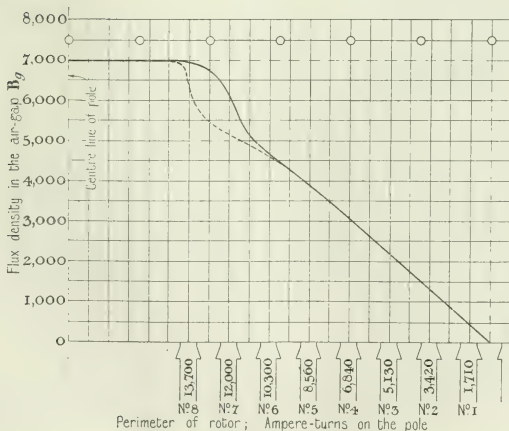


FIG. 4.

and then around the rectangle indicated by the dotted line. The ratio between these areas in Fig. 4 is 0.625.

In order to plot the no-load magnetization curve strictly one ought to go through this process of plotting the field

of  $K_f$  does not change very much with change in the exciting current. We may for practical purposes take the voltage as proportional to the maximum flux density in the gap. If this is done we can plot the no-load magneti-

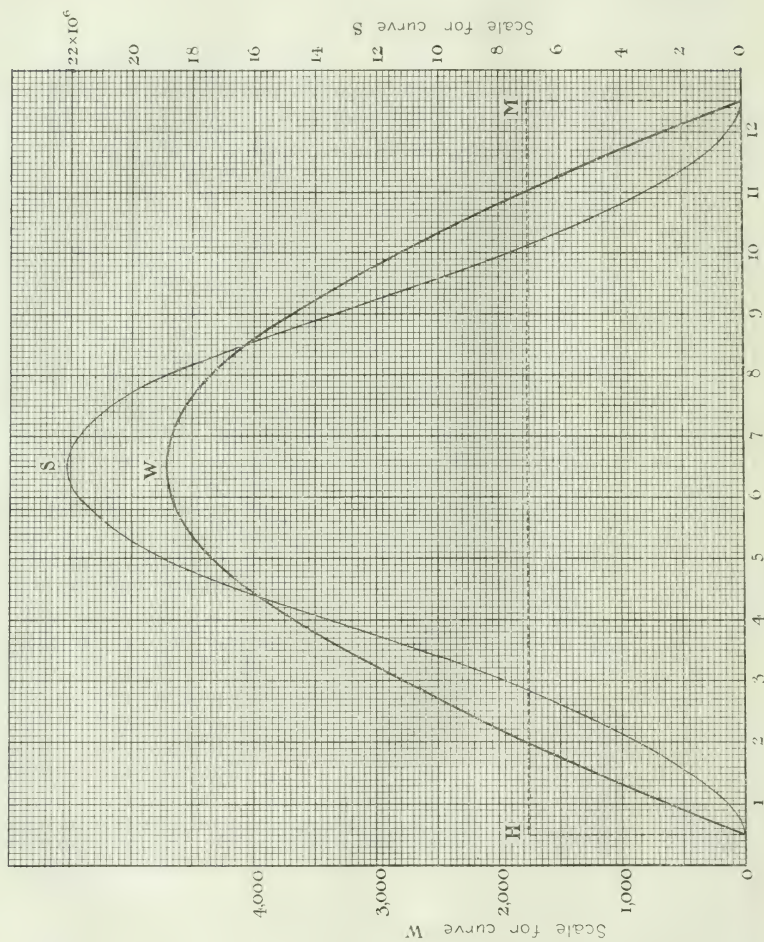


FIG. 5

zation curve from the figures given on page 255 for the ampere-turns on the central part of the pole for the voltages 6,000, 6,600, and 7,500. These are plotted in Fig. 6. The dotted curve gives the increased ampere-turns required to allow for the saturation of the polar projection at full load

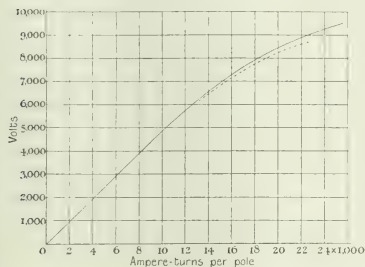


FIG. 6.

as explained on page 248. To find the ampere-turns at full load and 0.8 power factor one has recourse to the graphic construction given in Fig. 7. Here  $O E_T$  is the terminal voltage and  $O I_a$  is the lagging current laid out to a scale to represent the 11,000 armature ampere-turns per pole. The first step is to set off the armature impedance-drop

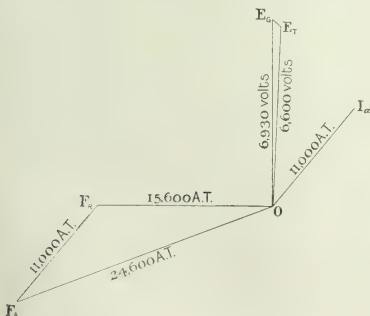


FIG. 7.

$E_T E_0$ . The value of the armature reactance-drop can be calculated in the manner given in Appendix III, but it is more usual to guess it, because it generally lies between 7 per cent and 10 per cent of the normal voltage, and in any case its effect upon the ampere-turns at full load is not very great. In this case it is 7 per cent of the normal voltage. The voltage-drop due to resistance is only one-third of 1 per cent and can be neglected in view of other

errors that arise from the uncertainty of the quality of the steel. The generated voltage  $O E_0$  in this case is 6,930 volts. Referring now to Fig. 7 we see that we require 15,600 resultant ampere-turns to generate this voltage. This is set off as a vector  $O F_R$  at right angles to  $O E_0$ . Then  $F_R F_A$  representing the 11,000 armature ampere-turns is set off parallel to  $O I_a$ , and we get  $O F_A$  the applied field ampere-turns required at full load.

## APPENDIX II.

CALCULATION OF THE VALUE OF  $K_p$ .

The method of calculating the value of  $K_p$  when the field-form and the arrangement of the armature conductors are given, can be illustrated by working out this coefficient for the 2,700-k.v.a. turbo-generator the field-form of which is given in Fig. 4.

In this case we have a 3-phase, star-connected armature, so that the voltage between two terminals is that generated in a band of conductors occupying two-thirds of the pole-pitch. It will in general be found sufficient to calculate  $K_p$  as if there were 12 slots per pole, since a larger number of slots per pole does not sensibly affect the result. The pole-pitch is divided into 12 parts, six of which are marked off by little circles in the half field-form shown in Fig. 4. We begin by taking the values proportional to the flux density in the gap opposite any group of eight circles, which may be taken to represent the eight conductors lying in the band. For instance, for one position of the eight circles, omitting one cipher, we may take the values

450
675
700
700
700
675
450
310
4,660

and this gives a figure proportional to the instantaneous voltage. When the field-magnet has moved through the space of one conductor, the voltage generated is proportional to the sum of the following values:—

675
700
700
700
675
450
310
155
4,365

By a successive process of addition and subtraction, we obtain figures proportional to the voltage generated in the phase-band as follows: 4,660, 4,365, 3,690, 2,835, 1,825, 675, — 675, — 1,825, — 2,835, — 3,690, — 4,365, — 4,660, — 4,660 — 4,365, etc. These values are plotted as shown in curve

W, Fig. 5; they give the wave-form of the electromotive force generated between the terminals of the 3-phase, star-connected winding.

The next step is to square the values of the ordinates of curve W and plot them to some convenient scale, as shown in curve S. Now the value of  $K_s$  is the ratio of the virtual value of the voltage actually generated in the eight conductors, with the field-form shown in Fig. 4, to the value of the voltage that one would get in a homopolar machine having a flux density equal to the maximum in Fig. 5, with 12 conductors in series. In order to avoid any question of the scales to which Fig. 5 is plotted, one may adopt the following plan: 12 conductors would have a generated voltage proportional to  $12 \times 700 = 8,400$ . The square of this is  $70^2 \times 56 \times 10^6$ . Plot this squared voltage, as shown by the dotted line in Fig. 5, to a scale one-tenth of that used for the curve S. A planimeter run around curve S gives a reading 1,322; a planimeter run around the dotted rectangle gives 860; this multiplied by 10 gives 8,600. Therefore the ratio of the square root of the mean square value of the voltage which is generated in the eight conductors to the square root of the mean square value which would be generated in a homopolar machine having 12 conductors is

$$\sqrt{(1322/8600)} = 0.392 = K_s.$$

It will be seen that this method is applicable to any arrangement of conductors.

### APPENDIX III.

#### CALCULATION OF THE MAGNETIZING CURRENT.

The magnetic circuit of a dynamo-electric machine, considered from the most general point of view, contains paths of various lengths. The magnetomotive force is not the same along all the paths. If we adopt formula (1), involving  $\Phi$ , the total flux per pole, and set out to calculate the ampere-turns necessary to drive this flux along the magnetic circuit, it is necessary to mark off a definite course along the circuit, the magnetomotive force along which is taken as a criterion for the whole circuit. This plan leads to considerable difficulties in the case of induction motors and other machines in which the magnetomotive force on the magnetic circuit varies very greatly according to the paths we choose.

Where, however, we adopt formula (3) and fix our minds, not upon  $\Phi$ , but upon the maximum density in the gap, we can confine our attention to one path along the magnetic circuit on which the magnetomotive force is a maximum.

In dealing with salient-pole machines, the method of calculating the ampere-turns per pole is the same whether we adopt formula (1) or formula (3). In the one case we add together the reluctances of the various parts of the magnetic circuit, each multiplied by the flux in that part, and arrive at the total magnetomotive force; in the other case we divide B in each part by the permeability of the material and multiply by the length of each part, and add together all the quantities thus obtained. The sum gives us the total magnetomotive force impressed upon the circuit.

It is clear that if we are dealing with a distributed

winding on both stator and rotor, the calculation is very much simplified when we need only consider the part on which the magnetomotive force is a maximum. The example given on page 247 indicates sufficiently well the method employed.

On a salient-pole machine with a simple magnetizing coil, the calculation of the exciting current offers no difficulty. With a distributed winding excited by a continuous current, the matter is conveniently dealt with in the manner indicated in Appendix I.

Where a magnetic circuit is excited from a 3-phase winding, the method of calculating the ampere-turns on the circuit has been fully dealt with by Dr. Kloss\* and by Dr. S. P. Smith and W. H. Barling.† The author finds it is convenient to express the results in somewhat different terms from those used by these authors. If  $I_m$  is the virtual value of the magnetizing current,  $Z_p$  the total number of conductors on the 3-phase armature, and  $p$  the number of pairs of poles, then the effective value of the ampere-turns per pole is  $0.43 I_m Z_p / 2p$ . Where the number of slots per pole is not great, the coefficient in this expression is somewhat increased. In the case where there are only 6 slots per pole, the coefficient becomes 0.437.

*Ampere-turns on the air-gap.*—The usual formula is:

$$\text{Ampere-turns on the gap} = B \times l_g \times K_g \times 10/4\pi,$$

where  $l_g$  is the length of the gap in centimetres, and  $K_g$  is the air-gap coefficient,‡ the introduction of which may be necessary on account of the presence of open slots in the rotor or stator.

*Ampere-turns on the teeth.*—No difficulty arises in calculating the ampere-turns expended on iron teeth where the sides of the teeth are approximately parallel. In this case one usually takes the density in the iron at a point one-third of the tooth-length distance from the narrowest part of the tooth. One-third is chosen instead of one-half because the bending over of the magnetization curve leads to the main part of the ampere-turns being expended on the narrow part of the tooth. Where, however, the sides of the tooth are far from parallel, and particularly if the saturation at the narrowest part of the tooth is very great, much greater precautions must be taken if we are to calculate the ampere-turns with any degree of accuracy. The method proposed by W. B. Hird,§ which is illustrated by the example worked out in Appendix I, will be found convenient.

A convenient method of calculating the apparent flux density in the teeth is to divide the total magnetic loading  $A$ , B by the total section of all the teeth. If we are dealing with teeth on a revolving armature, the process of finding the cross-section at a distance two-thirds of the tooth length from the perimeter is as follows:—

From the diameter subtract four-thirds of a tooth length, and multiply by  $\pi$ ; this gives what may be called the mean circle. Subtract from this the product of the width of the slots  $\times$  the number of slots, and obtain the sum of the widths of all the teeth. This multiplied by the net

\* *Electrotechnik und Maschinenbau*, vol. 28, p. 53, 1912.

† *Electrician*, vol. 74, p. 42, 1914.

‡ See papers by: F. W. CARLIER, *Journal I.E.E.*, vol. 20, p. 295, 1900, and vol. 34, p. 47, 1905; also *Electrical World and Engineer*, vol. 28, p. 884, 1911. C. C. HAWKINS and R. WIGHTMAN, *Journal I.E.E.*, vol. 29, p. 430, 1909. H. S. HELD-SHAW, A. HAY, and P. H. POWELL, *Ibid.*, vol. 34, p. 21, 1905.

§ *Journal I.E.E.*, vol. 20, p. 935, 1900.

length of iron gives the total section. Where we are dealing with the stator, it is usual to take the section of the teeth at one-third of a tooth length from the stator surface. In this case we add two-thirds of a tooth length to the diameter and get the diameter of the mean circle. This explains the process carried out in the calculation sheets on pages 250 and 251 under the heading "Teeth."

When the teeth are very highly saturated, the drop in the magnetic potential along the tooth is sufficient to drive a considerable amount of flux along the air space of the slots and ventilating ducts, so that the "apparent" flux density obtained above is greater than the actual flux density in the teeth. It is convenient to have curves giving the relation between the apparent flux density and the actual flux density for different values of  $K_s$ ;  $K_s$  is the ratio of the section of the iron plus the section of the air to the section of the iron. Curves of this kind are easily plotted for any material the magnetic properties of which are known.

It is unnecessary here to describe the methods of calculating the ampere-turns on the core and yoke, as these methods are dealt with fully in the text-books.

#### APPENDIX IV.

##### ARMATURE REACTION.

Armature reaction is properly considered under two headings. There is first of all the armature ampere-turns, and secondly the armature inductance, which calls for ampere-turns on the field-magnet to overcome the back electromotive force set up by it.

*Armature ampere-turns.*—The ampere-turns on a polyphase armature are best treated vectorially, as they operate in general partly as a cross-magnetizing influence and partly as a demagnetizing influence. It is not proposed to treat this matter here, as it is fully dealt with in the text-books. The amount of the armature ampere-turns can be calculated in the manner given by Dr. S. P. Smith and W. H. Barling in their paper referred to above. The author prefers the result in the form:—

$$\text{Total ampere-turns on the armature} = 0.43 I_a Z_m$$

where  $I_a$  is the virtual value of the armature current, and  $Z_m$  is the total number of conductors in a 3-phase armature.

##### ARMATURE INDUCTANCE.

In considering the armature reaction of a polyphase armature, we have to take into account not only the back magnetomotive force which it exerts, but also the back voltage that is generated in the winding by the leakage flux which passes across the slots and around the end-windings. A great deal has been written upon the method of calculating this leakage flux. Some writers advocate the very simple method of allowing so many lines per centimetre length of iron per ampere in the slot. This method, though advantageous from the point of view of saving time, does not help us in comparing the relative merits of two designs. Some of the methods which have been put forward are exceedingly complex and require the use of rather extensive formulae, the elaboration of which is hardly justified in view of the uncertainty of the result which arises from accidental variations in construc-

tion. Two machines built to the same drawings will sometimes show, on test, a difference as great as 7 per cent in their short-circuit currents. It would seem that some intermediate method which, while being short, yet takes into account all the most important quantities that control the result, is of most service in practice. The following method of calculating the leakage flux is employed by the author.

The leakage flux may be divided into four parts:—

- (1) The leakage across the stator slots;
- (2) The leakage across the rotor slots;
- (3) The zig-zag leakage;
- (4) The leakage around the ends of the coils both on rotor and on stator where they project from the iron.

In addition to these there is a certain amount of leakage which interlinks with both stator and rotor windings where the magnetomotive force of one does not balance that of the other.\*

*Slot leakage.*—The calculation of the amount of effective leakage across the slots is most easily carried out by means of the formula

$$\lambda_{sl} = \frac{1}{3} \cdot \frac{h}{h_c}$$

where  $h_c$  is the depth of the slot after a deduction has been made for the thickness of the insulation between the copper and the bottom of the slot, and  $b$  is the breadth of the slot. By  $\lambda_{sl}$  we denote the lines across the slot per centimetre of axial length of slot for unit magnetomotive force. To this must be added the leakage across the mouth of the slot.

Whether the slot is open or semi-closed, the permeance across the mouth of the slot can be found from Fig. 8. This figure is so constructed that a designer can tell at once from inspection the effect of changes in the shape of the lips upon the permeance. The shape of the lip is indicated by shading, as shown in the figure, and the shading may extend either to the line O A as shown, or to the line D C, or to the line O'2 B. The position of the small face  $\hat{p}$  may be varied, so that the fraction (mouth of slot)/(width of slot) has any value between zero and 1. At whatever point we choose to draw  $\hat{p}$ , it is only necessary to continue up the vertical line from  $\hat{p}$ , as shown in the figure, until it cuts one of the curves C', A', or B', corresponding to the depth of the lip, and we can at once read off the permeance  $\lambda_m$  per centimetre of axial length of slot. For example, in Fig. 8 the lip is supposed to be of the shape indicated by the shading, the value of (mouth of slot)/(width of slot) being 0.375. If we carry up the perpendicular from  $\hat{p}$  to the curve A', we find that the permeance in C.G.S. lines per cm. length of iron is 0.08. Had the lip been of a deeper design, so as to extend up to the dotted line D C, we should have carried our perpendicular up to the dotted curve C', and the permeance would then be found to be 1.2. If the lip is of a special shape, or has the angle of one of its faces different from that shown in the figure, it is easy to sketch on our figure a lip having the same permeance and having face angles enabling Fig. 8 to be instantly applied. Take the stator slot belonging to the 600-h.p. motor of which par-

\* W. ROGOWSKI and K. SIMON: "Leakage in Induction Motors," *Elektrotechnische Zeitschrift*, vol. 30, pp. 219 and 254, 1909.

ticulars are given on the calculation sheet, page 251. Here the value of  $h_s$  is 3.7, and  $b = 1.5$ .

$$\lambda_d = \frac{1}{3} \times \frac{3.7}{1.5} = 0.8.$$

Now the ratio  $m/b = 0.3/1.5 = 0.2$ , and the shape of the lip is such as to be bounded by the line OA in Fig. 8. Therefore  $\lambda_m = 1.13$  and  $\lambda_d + \lambda_m = 1.93$ . This value is entered near the bottom of the calculation sheet, page 251, as the permeance of the stator slot.

When calculating the leakage due to the rotor slot, it is convenient to multiply the sum of  $\lambda_d$  and  $\lambda_m$ , obtained in the way shown in the last example, by the ratio (No. of stator slots) : (No. of rotor slots). This enables the result to be added directly to the stator permeance, and the total

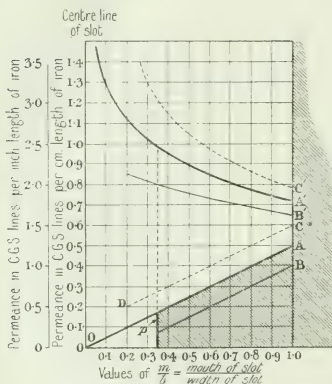


FIG. 8.

leakage can be calculated from the number of ampere-wires in the stator slot.

Take the rotor slot belonging to the 600-h.p. motor. Here the value of  $h_s$  is 3.0 cm., and  $b = 0.96$ .

$$d = \frac{1}{3} \times \frac{3}{0.96} = 1.05.$$

The ratio  $m/b = 0.3/0.96 = 0.31$ . Therefore  $\lambda_m = 1.2$ , and  $\lambda_d + \lambda_m = 2.25$ . Now there are 120 slots in the stator and 150 in the rotor, so that the total permeance of stator and rotor slots is

$$1.93 + \frac{120}{150} \times 2.25 = 3.73.$$

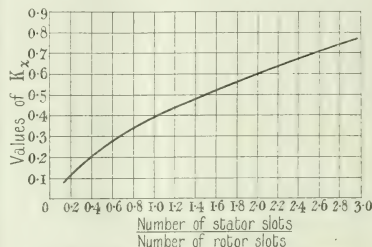
#### ZIG-ZAG LEAKAGE.

For roughly estimating the zig-zag leakage, a simple rule is given here, which works well enough in practice; though by reason of the fact that it does not take into account all the factors which affect the result, it cannot be regarded as strictly accurate. As we said before, if a method is not short, it is of no use in practical design. The rule here

given sacrifices all the minor refinements in order that it can be applied in 30 seconds. If designers require a more elaborate method, they are referred to the papers<sup>2</sup> quoted below.

The reluctance of the path of the zig-zag leakage is in the main proportional to the length of the air-gap. The width of the path changes as the teeth change their relative positions; but the maximum width of the path is one-half the width of the tops of the teeth where these are equal in stator and rotor, and where these are unequal it is a function of the widths of the tops of the teeth.

If we assume that the dimensions of the teeth and the mouths of the slots are such as one generally finds in practice, it is possible, roughly, to take into account the change-

FIG. 9.—Values of  $K$ , for estimating Zig-zag Leakage.

ing width of the leakage path by means of a coefficient,  $K_z$ , and we may write

$$\lambda_z = K_z \times \frac{\text{pitch of slot}}{2} \times \frac{1}{\text{length of gap} \times K_s}$$

where  $\lambda_z$  denotes the lines of zig-zag leakage per centimetre axial length of slot, for unit magnetomotive force applied

<sup>2</sup> R. GOLDSCHMIDT: "Leakage Problems of Induction Motors," *Electrician*, vol. 69, pp. 236, 352, 430, 507, and 624, 1907-8. C. A. ADAMS: "Design of Induction Motors," *Transactions of the American Institute of Electrical Engineers*, vol. 24, p. 610, 1909. R. E. HELLMUND: "Leakage Factor of Induction Motors," *Electrical World*, vol. 50, p. 1004, 1907, and vol. 51, p. 179, 1908; *Electrical Review* (New York), vol. 52, p. 172, 1908; *Elektrotechnische Zeitschrift*, vol. 30, p. 25, 1909, and vol. 31, pp. 1111 and 1140, 1910; *Journal I.E.E.*, vol. 45, p. 239, 1910. W. OELSCHLAGER: "Predetermination of Short-circuit Current of 3-phase Induction Motors," *Elektrotechnische Zeitschrift*, vol. 38, p. 1230, 1908. H. M. HOHART: "Determination of the Circle Coefficient of the Induction Motor," *Electrical Review and Western Electrician*, vol. 55, p. 1073, 1909. U. KLOSS: "Calculation of Overhang Stray Flux in Induction Motors," *Elektrotechnik und Maschinenbau*, vol. 28, p. 53, 1910. W. ROGOWSKI: "Leakage of Induction Motors," *Elektrotechnische Zeitschrift*, vol. 31, pp. 1202 and 1316, 1910. A. M. GRAY: "Induction Motor Design Constants," *Electrical World*, vol. 58, p. 1599, 1911. J. REZELMANN: "Reactance of Induction Motors," *Electrician*, vol. 66, p. 857, 1911. F. NIETHAMMER and E. SIEGEL: "Doubly-linked Dispersion of Asynchronous Motors," *Elektrotechnik und Maschinenbau*, vol. 29, p. 635, 1911. G. BENTSCHKE: "Experimental Determination of Leakage Factor of Transformers and Induction Motors," *Elektrotechnische Zeitschrift*, vol. 31, pp. 1202 and 1316, 1910. H. MEYER-WÜLFING: "Air-gap Leakage Fluxes in 2-phase Motors and in 3-phase Motors with 2-phase Rotors," *Archiv für Elektrotechnik*, vol. 1, p. 363, 1912. L. D. JONES: "Tests on Induction Motors designed with Deep Rotor Slots," *General Electric Review*, vol. 1, p. 230, 1913. E. A. BUEBENS: "The Estimation of the Dispersion Coefficient of 3-phase Induction Motors and Its Application to Their Design," *Electrician*, vol. 76, p. 51, 1915.

across the mouth of a stator slot. The values of  $K_s$  which may ordinarily be employed in practice are given in Fig. 9 as a function of the ratio (No. of stator slots):(No. of rotor slots).

The slots in the stator and rotor of a 600-h.p. motor are shown on the calculation sheet, page 251. The air-gap ( $g$ ) = 0.2 cm.; the contraction coefficient ( $K_p$ ) = 1.18; the pitch of the stator slots = 2.6 cm. There are 120 slots in the stator (6 conductors per slot) and 150 slots in the rotor. To find the permeance due to zig-zag leakage per centimetre length of slot we have  $120/150 = 0.8$ ; and, from Fig. 6,  $K_z = 0.34$ .

$$\lambda_z = 0.34 \times \frac{2.6}{2 \times 0.2 \times 1.18} = 1.87.$$

If we now add together the permeances due to the stator slot, the rotor slot, and the zig-zag path per centimetre of axial length, and multiply by twice the length of iron, we arrive at an approximate figure for the permeance of the path of magnetic leakage from one pole, so far as the first three parts of the leakage above referred to are concerned. Leaving out of account for the moment the leakage due to the end-windings, we can get the leakage in the iron paths in C.G.S. lines per pole by multiplying the total permeance calculated above by the maximum ampere-wires per slot and by 1.257.

In the 600-h.p. motor, we have :—

Permeance of leakage path across stator slot	= 1.93
" " " " rotor "	= 1.8
" zig-zag leakage path ...	= 1.87
Total ... ..	5.6

Taking the particulars of the motor given on page 251 :

Axial length of iron = 46 cm.

The permeance of the path =  $5.6 \times 46 \times 2 = 515$ .

For a stator current of 1 ampere the leakage flux along the above paths is  $515 \times 1 \times 1.41 \times 6 \times 1.257 = 5,460$ .

The flux per pole leaking between the iron teeth for 1 ampere per phase in the stator we will denote by  $\Phi_s$ . It is the sum of the slot leakage and the zig-zag leakage when 1 ampere is passing in the stator. In the example given above,  $\Phi_s = 5,460$ .

**Leakage around the end-windings.**—The only really accurate way of finding the value of the end leakage of an induction motor is by experiment on the winding in question. If we have two motors built on the same frame with the same type of winding, but one machine much longer than the other, we can, by measuring the short-circuit current on each machine, calculate with some accuracy what part of the leakage reactance in each machine is due to the end-windings.

When once this has been ascertained it can be put on record and the figure used in similar cases. In default of values found by experiment, it is desirable to have a simple method of finding roughly the amount of end leakage that may be expected on a given machine.

It will be seen that, while there are very many types and shapes of windings on induction motors, there are properties common to all the types found on commercial machines which make it possible to give approximate

constants for the estimation of the end leakage. In the first place, where the coils are very deep they usually project a very long way out from the core; so that while the mean line of path encircling the coils is increased, the area of the path is increased in about the same proportion. Thus, for a given type of winding, say that illustrated in Fig. 10, the leakage per centimetre of perimeter will be about the same for the same ampere-turns per pole, independently of the size of the coils, always supposing that they are made to the same drawing but to different scales. On the other hand, there is a great deal of difference between the amount of end leakage from coils of different types. It has been found by experiment (as is, indeed, obvious from inspection) that coils of the barrel type do not give half as much end leakage as coils of the concentric or chain type, as illustrated in Fig. 10. It will be sufficient for our purpose to introduce certain coefficients to take care of the characteristics of the different types of coils, and to include in our formula only those factors which have the greatest influence on the leakage per pole, assuming that the coil

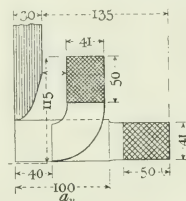


FIG. 10.

is of a standard type. As we are concerned in this formula with the leakage per pole, one of the main factors is the pole-pitch. Where the pitch is short and the coils project a long way from the iron, there is a great deal of sideways leakage that ought to be taken into account in the formula.

The amount of end leakage depends not so much upon the number of ampere-wires per slot, as upon the total number of ampere-turns per pole. The nearer the rotor and stator windings lie together, in order to neutralize each other in the creation of a magnetic field, the less will be the end leakage. Thus, if we have a barrel winding on both stator and rotor, the end leakage will be much less than if both rotor and stator windings are turned away from each other towards the iron. The further the windings project from the frame, the greater will be the leakage. The proximity of the iron parts, including the end plates and fenders covering the winding, greatly affects the end leakage.

The whole matter is so complicated by accidental circumstances that it is useless to attempt any accurate calculation. In order to arrive at some rough idea to serve as a basis of calculation, we may divide the types of end windings into four separate classes, as shown in Table 2. To each combination of one type of stator winding with one type of rotor winding we may attach the coefficient  $K_L$  given in the table. These coefficients

can then be used in conjunction with the following formula:—

End leakage in C.G.S. lines per pole on both ends of machine

$$\Phi_e = K_L \times (l_p + a_v) \times \text{virtual ampere-turns per pole,}$$

where  $K_L$  has a value somewhere between 1.8 and 3.5, depending on the type of winding, as shown in the accompanying table, and

$$l_p = \text{pitch of poles in cm.,}$$

$$a_v = \text{average overhang of coils in cm.}$$

In Fig. 10 the average overhang of the coils is 100 mm., so that  $a_v = 10$  cm.

The virtual ampere-turns per pole are taken in the following manner: Take the total number of conductors per phase per pole and multiply by the virtual amperes per conductor.

The end leakage on one pole really depends on how the end windings are arranged on that pole. There will be a difference, for instance, between the amount of flux encircling a hemitropic winding and the flux encircling a divided coil winding. If, however, we take the ampere-turns as directed above, and remember that it is the total leakage on two poles that must be taken into consideration, it will be found that the above method gives values which are near enough for practical calculations. The hemitropic winding usually has a larger value of  $a_v$  than the divided coil winding, and in that respect gives rather greater values for end leakage.

TABLE 2.

Values of  $K_L$  for End Leakage of 3-phase Motors with Normal Full-pitch Windings.

Type of Rotor Winding	Type of Stator Winding		
	Barrel	Mush	Concentric
Squirrel-cage... ..	1.8	2.6	2.8
Barrel ... ..	1.4	2.4	2.45
Mush ... ..	2.2	3.1	3.2
Concentric ... ..	2.45	3.2	3.5

*Example.*—In the 600-h.p. motor, particulars of which are given on page 251, the pitch of the poles,  $l_p$ , is 31 cm., and the average overhang,  $a_v$ , of the coils is 12.5 cm. There are 4 slots per phase per pole, and 3 conductors per slot, so that for 1 ampere per phase we have the virtual ampere-turns per pole =  $4 \times 3 \times 1 = 12$ .

The type of winding is "concentric" on the stator and "barrel" on the rotor; and from Table 2 we get  $K_L = 2.45$ . Therefore the end leakage per pole is

$$\Phi_e = 2.45 \times 43.5 \times 24 = 2,560 \text{ C.G.S. lines.}$$

If the stator and rotor windings had no resistance and the short-circuit current were only limited by the reactance caused by the leakage flux, the value of the short-

circuit current would be that value which would be great enough to produce a leakage flux equal to the working flux. If we denote the total leakage per pole produced by 1 ampere by the symbol  $\Phi_l = \Phi_s + \Phi_r$ , and if we denote the working flux per pole by  $\Phi_m$ , then the value of the short-circuit current assuming no resistance would be  $\Phi_m / \Phi_l$ .

In the motor in question we have

$$\frac{5.5 \times 10^6}{8,020} = 680 \text{ amperes per phase.}$$

The volts per phase are 1,430, and the reactance per phase is therefore

$$\frac{1,430}{680} = 2.1 \text{ ohms.}$$

The method of calculating the apparent impedance of the stator and of finding the other quantities necessary to lay out the circle diagram is sufficiently indicated on the calculation sheet (page 251).

## APPENDIX V.

### LOSSES IN COPPER AND IRON.

The methods of calculating the copper losses in electrical machines are fairly well standardized, and it is unnecessary to consider them here. Attention should be drawn to the necessity of calculating the eddy-current losses in solid conductors, and for this purpose the curves given by A. B. Field in his paper before the American Institute of Electrical Engineers\* are of very great service in shortening the work.

So far as the iron losses in the machine are concerned, it is impossible to determine these beforehand with any degree of accuracy. Experience shows that two machines built to exactly the same drawings and, so far as can be ascertained, with the same care, will have widely differing iron losses, owing to small accidents in the handling of the iron stampings. It is therefore not worth while to make a very elaborate calculation of iron losses; many engineers use a curve giving the combined hysteresis and eddy-current losses per cubic centimetre at different maximum flux densities. Such curves, to be of service, should be based on the average results obtained from running machines, rather than on purely theoretical considerations. The author has seen curves of this kind plotted on the assumption that the eddy-current losses increase in proportion to the square of the flux density, and the hysteresis losses in proportion to  $B^{1.6}$ . Such curves will be found in practice to give too high values for the loss in the iron at

\* A. B. FIELD: "Eddy Currents in Large Slot-wound Conductors," *Transactions of the American Institute of Electrical Engineers*, vol. 22, p. 704, 1905. In *Journal I.E.E.*, vol. 33, p. 1125, 1904, the matter is still further elaborated by Mr. M. B. Field, and some practical cases are considered. P. GIRAULT: "Eddy-current Losses in Armature Conductors," *Lumme Electropia*, vol. 4, p. 35, 1908. F. EMDE: "On the Distribution of Alternating Current in Slots," *Elektrotechnik und Maschinenbau*, vol. 29, pp. 703 and 726, 1908. F. RUSCH: "Skin Resistance Losses in Alternator Windings," *Elektrotechnik und Maschinenbau*, vol. 28, pp. 73 and 98, 1910. ANGERMANN: "Eddy Currents in Solid Armature Conductors," *Elektrotechnik und Maschinenbau*, vol. 28, p. 675, 1910. W. ROTGOSNICK: "Copper Losses in Alternating-current Machines," *Archiv für Elektrotechnik*, vol. 2, p. 81, 1913.

very high densities, because the hysteresis loss does not increase as  $B^2$  at high densities. In fact, it has been shown that where the magnetic field is a rotating magnetic field, the hysteresis loss is zero for flux densities above 22,000; and even for an alternating field it becomes almost constant for densities greater than 22,000. In most electrical machinery the field is partly rotating and partly alternating, and we may certainly take it that the hysteresis loss does not increase at all at high flux densities such as are used in the teeth of continuous-

the losses with sufficient accuracy for commercial purposes.

Iron-loss tests taken on completed machines will generally show greater losses than are given by these curves, particularly at high flux densities. It would appear that when the teeth of a machine become saturated, the flux from the poles bulges out sideways and attacks the armature from the ends, making eddy currents in the end-plates, so that the loss sometimes increases in ratio greater than the square of the flux density. This

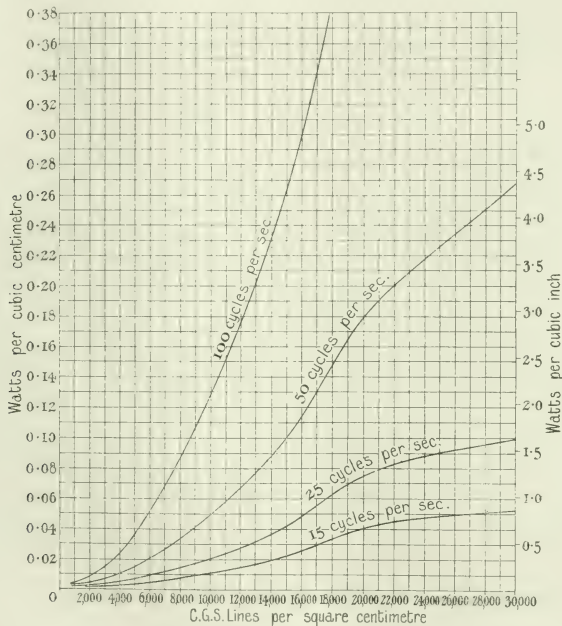


FIG. 11.—Iron-loss Curves.

current generators. It thus comes about that for low frequencies the curves giving combined loss take a shape somewhat like the curve shown in Fig. 11, a curious inflection occurring at  $B_s$  about 20,000. These curves are plotted for ordinary dynamo steel of a thickness of 0.04 cm. and subjected to as careful treatment as is consistent with ordinary shop processes. The losses shown in the curve are about twice as great as the theoretical losses calculated from the tests on samples having no burrs or short-circuits such as commonly occur in the built-up machines. Experience shows that curves of this kind will usually give

end-plate loss should really be allowed for separately, as its amount will depend upon factors different from those taken into account in calculating the true iron loss. A good deal of experimental work still remains to be done before we can formulate a method of calculating these end-plate losses.

Where special silicon steel\* is employed, the losses may

\* W. F. BARRETT, W. BROWN, and R. A. HADFIELD: *Transactions of the Royal Dublin Society*, vol. 7, p. 67, 1900; also *Journal I.E.E.*, vol. 31, p. 174, 1902. S. GUTHRIE: *THE MAGNETIC PROPERTIES OF IRON ALLOYS and their Uses in Alternate Current Design*, ELKINGTON, vol. 64, p. 530, 1909.

be reduced by 40 per cent when working at a flux density of 10,000 per sq. cm. at a frequency of 50 cycles, the thickness of the iron being 0.05 cm.

#### APPENDIX VI.

##### PREDETERMINATION OF TEMPERATURE RISE.

In a previous paper before the Institution the present author, in conjunction with Mr. H. D. Symons,<sup>\*</sup> gave certain rules for the predetermination of the temperature rise in various parts of electrical machines; and since that time further experiments have been made, particularly in connection with the passage of heat from the walls of ventilating ducts to the air passing along the ducts, and also in connection with the cooling of field coils.

the ventilating duct, through which the air moves at a much lower velocity; and (3) the external surface, part of which is presented to the cast-iron frame and part exposed to the slowly-moving external air.

(1) *The heat dissipated from the cylindrical surface.*—This depends very greatly upon the peripheral speed of the machine. Experience shows that we may adopt the rule:

$$\text{Watts per sq. cm.} = \frac{\text{Temp. rise } ^\circ\text{C} \times (1 + 0.1v)}{333}$$

where  $v$  is the peripheral velocity in metres per second of the moving armature or field.

(2) *The heat dissipated from the ventilating ducts.*—Two different kinds of ducts are commonly found in electrical machines. There is (a) the radial duct made by putting a

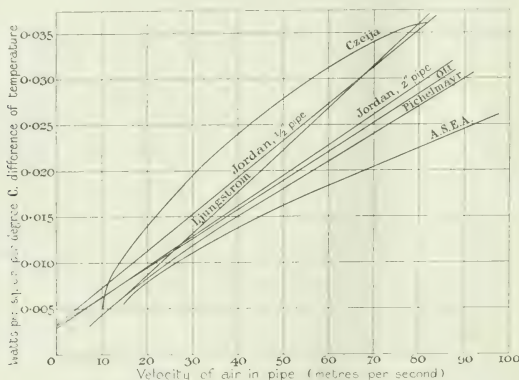


FIG. 12.—Relation between Heat Dissipated and Velocity of Air.

The temperature rise of the stator iron of an alternating-current generator or motor may be roughly predetermined in the following manner:—

The iron losses in the teeth and in the iron behind the teeth should be calculated first of all; to these iron losses should be added the copper losses occurring in the conductors lying in the slots, here called the "buried copper" losses. We may take it that these total watts are dissipated from the various surfaces of the stator. An investigation of the amount of heat dissipated by every surface of the stator, taking into account all the circumstances which might claim the attention of the physicist, would lead to a calculation far too lengthy and cumbersome to be tolerated in commercial design. We may, however, without undue refinement, consider broadly three kinds of surfaces which are found in most machines. There is (1) the cylindrical working face or internal bore of the stator, over which the air is in rapid motion; (2) the surface of

ventilating plate or spacing plate between the stampings allowing the air to pass in a radial direction from the air-gap to the external frame; and (b) the axial ventilating duct, consisting of a round or oblong hole in the stampings, enabling the air to travel in a direction parallel to the axis of the machine.

Experiments with both types of duct indicate that the specific cooling constant,  $h_m$ , is dependent not only upon the mean velocity of the air through the duct, but also upon the character of the motion of the air. Where the air moves in even stream-lines from one end of the duct to the other, the cooling conditions are very much poorer than where the air is broken up into eddies. The cooling conditions for the same amount of air passed through the duct may be three or four times as great where there are considerable eddies as where the air moves in even stream-lines. This circumstance makes experiments upon the specific cooling constant in ventilating ducts somewhat difficult and inconclusive, and is the cause of the wide

<sup>\*</sup> *Transactions I.E.E.*, vol. 48, p. 947, 1912.

divergences in the results obtained by different experimenters.

The curves given in Fig. 12 show the results arrived at by various inquirers<sup>22</sup> who have sought to determine the relation between  $h_v$  and the mean velocity of air passing along a ventilating duct. In most cases no distinction is drawn between narrow ducts and wide ducts, though there is no doubt that the width of the duct is quite an important factor.

In order to arrive at more definite values than seemed to be possible from the results plotted in these curves, the author and Mr. W. H. Blythe made a number of experiments with various kinds of ducts over a considerable range of air velocity and under varying conditions. The results of these experiments are contained in a contribution presented to the Institution, and as they are rather lengthy they are better published in a separate contribution than in this appendix.

These results can be shortly stated as follows:—If we denote the flow of heat from the walls of the ventilating duct, expressed in watts per square centimetre per degree C. difference of temperature between wall and air, by the symbol  $h_v$ , then we find that over a wide range of speed  $h_v = K_v v$ , where  $v$  is the mean velocity of the air in the

<sup>22</sup> K. ZEPPELIN, "Entwicklung der Belüftungsmaschinen von gasförmigen Dynamomessungen," *Elektrische Zeitschrift*, vol. 33, p. 318, 1912. L. OTT, "U.D.I. Mitteilung und Forschungsbericht, Nos. 15 and 29, p. 55, also "Zur Frage der Erwärmung elektrischer Maschinen," *Elektrische Zeitschrift*, vol. 29, p. 104, 1908. K. FRIEDLMEYER, "Elektromaschinenbau," *Elektrische Zeitschrift*, vol. 34, p. 318, 1913. J. T. NIXON, "The Laws of Heat Transmission," *Lectures at the Institution of Mechanical Engineers*, vol. 10, p. 199, 1909. H. P. JORDAN, "Rate of Heat Transmission between Fluids and Metal Surfaces," *Proceedings of the Institution of Mechanical Engineers*, p. 1317, 1909.

duct measured in metres per second, and  $K_v$  is a constant depending on the character of the duct.  $K_v$  is very much affected by the amount of baffling of the air in the duct. A circular duct 2 in. in diameter gave a value of  $K_v$  as low as 0.00033 when the air passed through with long steady stream lines, but the addition of baffles brought the value up to 0.0011. For ordinary flat ducts about  $\frac{1}{4}$  in. wide it would seem that the constant  $K_v$  may be anything from 0.0005 to 0.0014, depending on the amount of eddy currents in the air in passing along the duct. Where the ducts are dirty, the value of  $K_v$  may be very much lower still.

*Cooling of the external surface of stators.*—The cooling of the iron of the stator is considerably helped by the conduction of the heat into the cast-iron frame, from which it is passed by radiation and convection to the surrounding air. On low-speed machines in which the depth of the punchings is usually small compared with the diameter of the frame, this cooling by conduction to the yoke is of more importance than on turbo-generators with very deep punchings.

It is generally impossible to make an accurate calculation of the amount of this conduction, and yet one must make some allowance in the case of machines with shallow iron. Perhaps the simplest rule in machines of normal construction is to allow a certain number of watts per square centimetre of external surface, the amount being found by experience with the type of frame employed and on the temperature rise permissible. The author has found that with ordinary box-type cast-iron frames, with the punchings dovetailed into the cast iron, to allow 0.15 watt per square centimetre is suitable where a temperature rise of 40 degrees C. is permissible.

## DISCUSSION BEFORE THE INSTITUTION, 13 JANUARY, 1916.

Professor SILVANUS P. THOMPSON: The author has at various times helped us to get to the bottom of some of the more complicated problems which present themselves in dynamo design, and has again laid us under a debt of gratitude. On this occasion, knowing some of the limitations of the subject, one almost feels inclined to think that the author may be too minute. One likes to see formulæ and data that go down to the third place of decimals, which presume, I suppose, that there is an accuracy of something like 1 in 1,000 in the methods of calculation. All this precision of theory is defeated, however, by discovering that the steel-makers will not guarantee iron to within 1 per cent, and possibly not within 2 or even 3 per cent, of what it is supposed to be. However, in spite of the difficulties that are presented by the inability of the designer to rely with any degree of accuracy upon the quality of the material, it is perhaps well to have the theory precise in all details. First, I should like to say how very much I appreciate the paragraph at the bottom of page 246 and the beginning of page 247: "Any general method of design should in its nuclear form be exceedingly short, and capable of reaching rough results in the course of a few minutes. . . . Moreover, a general system of calculation should be founded upon sound principles and not merely built upon empirical rules." The whole of that paragraph could not, I think, be bettered. It was some sense of this which a dozen years ago or more made me anxious to put

certain empirical rules which were useful, acceptable, true, and generally known, upon a more scientific basis. In particular I speak of the rule invented 25 years ago, and brought before this Institution by Mr. W. B. Esson, a fundamental rule in design which has become known as "Esson's Rule":—That the output of a machine at a given speed depends upon the square of the armature diameter and on the length of the core. This D<sup>2</sup>L rule is fundamental; and in practice we use a coefficient to express the proportionality. Suppose we know the kilowatts, KW, of a machine and the speed, R P M, at which it is to run; then the kilowatts per revolution per minute are proportional to D<sup>2</sup>L, where D is the diameter and L the length of the core. That is an empirical rule pointed out by Mr. Esson without any theory at all, so far as I know. He made experiments on the old Paterson and Cooper dynamos and others of different sizes, different speeds, and different outputs, and found there was such a proportion. The rule in symbols may be written

$$D^2 L = \frac{KW}{RPM} \times \xi,$$

where the Greek letter  $\xi$  is the output coefficient. If the dimensions are in inches, then the value of that coefficient—I am speaking of continuous-current machines—varies from a minimum of somewhere about 25,000 in new machines to a maximum of something like 70,000 in small

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and old machines.\* This rule has important applications in the factory, which are most useful in practice, because it enables us to calculate from machines of one size to those of another.

Some 15 years ago I said to myself: Here is an empirical rule; there must be some reason for it; there must be something behind this formula, since that coefficient  $\xi$  necessarily depends upon the quality of the iron, the degree to which it is magnetized, the amount of current that is carried by the armature, and, amongst other things, upon the degree to which the whole periphery is utilized for the magnetism. If we use poles that are too narrow in their embrace, we waste a lot of the surface by having too much space between the tips of the poles, and we are not getting as much out of the armature as we ought to obtain. I found that using inch units one could substitute for the empirical coefficient a rational coefficient.

$$\xi = \frac{60 \cdot 8 \times 10^9}{B \times q \times \psi};$$

where  $B$  is the mean flux-density over the pole-face,  $q$  the specific electric loading of the armature in ampere-conductors per inch of the periphery, and  $\psi$  the ratio of the pole-span to the pole-pitch. In modern continuous-current machines the numerical values of these quantities are: for  $B$  50,000 or 60,000; for  $q$  from 500 to 600 or more amperes per inch of periphery; for  $\psi$  about 0.75. If we assume these higher values, the resulting value of  $\xi$  is 27,000. That formula has nothing empirical about it, and depends purely on engineering facts. It is only one example of the way in which we may substitute scientific values for the empirical values when we have analysed the facts on which the empirical values depend. We see now that this coefficient, on which the size and cost of the machine depend, can be reduced in any machine by utilizing a greater proportion of the periphery by having broader pole-pieces; by employing greater specific electric loading; by having a larger value for the flux density; so making better use of our iron and copper. It is a question of using the iron and copper to the best advantage. And so we might go through a number of the very useful empirical formulæ invented from time to time and find out the scientific matters on which the empirical quantities depend. In fact we now can see how to amend the empirical constants by changing one or other of the things that enter into them to a better value, so getting better conditions for the utilization of our materials.

I now come back to the author's earliest point, namely, his comparison of the two sets of formulæ. In the first he employed the flux per pole, the cyclic speed, or number

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of revolutions per minute. He compared that formula with a second, wherein we deal with the maximum flux density under the pole and the surface speed. They are both useful and valuable formulæ. Apparently if we were limited to those two types of formulæ the author would prefer the second. To have a formula, for preference in form like the first one but having details in common with the second one, is no doubt an improvement; but it is not the only or the earliest way of putting together a formula which has those advantages. Suppose we write the formula in the following shape:—

$$E_c = \frac{f}{c} \times \frac{RPM}{60} \times Z \times \Phi \times 10^{-8};$$

where  $f$  is the number of poles,  $c$  the number of circuits through the winding of the armature, and the other symbols are those used by the author. Now multiply through by  $I$ , the whole current; and we get an expression for the whole output of the machine, namely

$$E_c I = \frac{f}{c} \times \frac{RPM}{60} \times Z \times I \times \Phi \times 10^{-8}.$$

We can easily convert that into the form suggested by the author in Section (5) of page 246: thus

$$E_c I = f \Phi \times Z \times \frac{I}{c} \times \frac{RPM}{60} \times 10^{-8};$$

where the first term on the right-hand side is the total magnetic loading on which the size of frame depends; the second the total electric loading on which, for an armature of given length, the weight of copper depends; and the third term is the speed. As I happen to have been using these formulæ for something like 15 years, I welcome them as familiar acquaintances. I am the last person to suggest that the author's formulæ are wrong, because I think they are essentially right. The only point of difference between these formulæ and those in the form which the author has put before us is this: he prefers to consider  $B$  to be not the average flux density, but the maximum flux density, because the maximum has some relation (in alternating currents) to the wave-form. If, however, after taking  $B$  as the average value, why should I not change it to be the maximum value and introduce another factor? The author says that if we could use the maximum flux density at every point all round the periphery the loading of that frame would be an ideal quantity which we should strive to obtain if we wished to make the plant efficiency as high as possible. We cannot, however, have the maximum density at every point: we must have wave-forms, and there must be neutral points as we pass from pole to pole; consequently we always fall short of the ideal. The ideal may be expressed in terms either of the maximum or of the average; it does not matter which, as long as we employ the right coefficients. If the author takes the maximum and reduces it down by a coefficient when he desires to express things in terms of an average density, why may not one equally well use a mean value, and multiply it up by a coefficient when the occasion arises to express things in terms of a maximum density? That brings me to the meaning of  $\psi$ , the ratio of the pole-span to the pole-pitch. It was a very simple quantity in old times, when poles were definite; say a salient pole with a

\* Esson, in 1891, gave the following values of the output coefficient, or rather gave values in terms of centimetre units which if translated into inch units have the following values for machines at that date:—

For cylindrical ring armatures	...	...	...	72,000
For drum armatures	...	...	...	50,000
For alternator armatures	...	...	...	122,000

His formulæ are given on p. 272 of vol. 20 of the *Journal*.

Mr. Albion T. Snell (*Journal I.E.E.*, vol. 19, p. 107, 1890), using Esson's rule found values of 100,000 for cylindrical ring armatures and 60,000 for drum armatures.

In 1896 in the fifth edition of my "Dynamo-electric Machinery," p. 386, discussing Esson's rule, I found the values of 82,000 for rings and 60,000 for drums. Nowadays any continuous-current machines which have a coefficient greater than 30,000 are looked upon as being unnecessarily large for their output.

practically uniform gap between it and the armature. But in the machines that we now have to deal with, with split poles, and poles with teeth and distributed windings around the various parts, what is the pole-pitch and what is the pole-span? One has to think about both of them, as well as about the ratio between the two. A new interpretation is obviously wanted. What the author has done is to take the method of Hird for dealing with one of these rotors with teeth on it and calculating the distribution of the surrounding field; and he has shown us how from that to build up graphically the curve of the electromotive force in any single conductor that the rotor pole may be passing. He then invites us to take the squares of the ordinates, so obtaining a new curve which then is to be planimeted, and the square-root of the mean ordinate used as the height of a rectangle. It is an excellent method. It results in our having to find the ratio between two areas which stand on the same base-line. Again, that is a thing which has been done in another way for years. It is this. Suppose we find that the flux distribution is of some irregular form within the limits of the pole-pitch. Take for example the author's Fig. 4. What is the breadth of pole? Not the piece that is nearly horizontal across the top. The breadth of the equivalent pole is a more or less ideal quantity: but when the curve has been obtained, instead of finding the mean height by flattening it down over the same breadth, we may just as logically find the rectangle of reduced breadth that shall be of the same height as the top of the curve is. That reduced breadth is the equivalent or ideal breadth of the pole. I do not see very much difference between squaring off the curve at the sides and squaring it off at the top. Either process is easily carried out; but the ratio in the particular process I am suggesting has the same meaning as it used to have in the old days when there were definite pole pieces. It is the ratio of the ideal pole-span to the pole-pitch which we take account of by using the coefficient  $\psi$ . But whether we adopt one method or the other, the important thing is to obtain the working result.

One of the author's most ingenious dodges is the device which he reduces to simple arithmetic by adding series of numbers: the solution of the problem how to find in a distributed winding the electromotive force form that results from a pole field-curve of some particular shape. Formerly the process involved a laborious graphic construction. Suppose we have before us some curve as the curve of the field-form or (what is the same thing) the electromotive force generated in a single conductor as the pole moves past it. What we want to find out is the form of the resultant wave for a winding of several conductors distributed over a certain breadth. Graphically one draws a number of identical curves, displaced laterally in correspondence with the distribution of the conductors; and then by summing the ordinates of these curves at a number of points along the base line we obtain as resultant a new wave-form which will generally require to be reduced to a different scale. Useful as this process is, and excellent as the arithmetical reduction is in the author's particular method, there is one feature about it which I do not think has ever been referred to—at any rate I have never seen any discussion of it. It is a very curious but well-known fact

among machine designers that, however a pole may be shaped and however irregular is the original field-form curve, the resultant wave-form of the electromotive force in the distributed winding is *always* much more nearly like a sine curve than the original curve was. What is the reason of that? I do not think it has ever been explained. I have no doubt that the author knows the reason, but I have not heard him mention it. If we take any form whatever, repeated over consecutive pole-pitches, we may consider it as constituting a periodic series; and it may therefore be regarded by Fourier's theorem as a periodic function consisting of a fundamental and a number of higher harmonics. Let us regard it in that way as a whole series of harmonics, and then consider what happens when we compound a number of such series together, all series being identical but spaced out at short distances, that is to say differing by small equal phase-differences from one another. The fundamentals are the only ones that will compound to a final sine curve, and that resultant curve of the fundamentals will have a resultant amplitude less than the sum of the amplitudes. If, for example, there are two conductors, or two sets of conductors, distributed in 2 slots say at  $20^\circ$  apart, then, because there is that slight phase-difference between their respective electromotive forces, their resultant electromotive force when joined in series will not be double of that in either of them, but will be only 1.97. This is on the supposition that the original curve is a pure sine-curve. But if a third harmonic is present, of any amplitude whatever, the amplitude of the resultant third harmonic will be multiplied, not to 1.97 but only to 1.73 times the amount of the original amplitude, because a difference of phase of  $20^\circ$  between the fundamentals is equivalent to a difference of phase of  $60^\circ$  for the third harmonic. Similarly, whatever is the original amplitude of the fifth harmonic, the resultant amplitude will be multiplied to 1.286 times; that of the seventh harmonic to 0.685; while that of the ninth harmonic will be reduced to zero. With a different angular breadth between the conductors, the multipliers will be different: but we see by this simple example how the mere act of distributing the conductors necessarily reduces the harmonics relatively to the fundamental. With a whole broad band of conductors the reductions are still more striking.

In conclusion I should like to thank the author for putting these things before us with all the experience of a large manufacturing establishment. There is only one other thing which I should like to say, and that is a point of criticism. I am doubtful whether it is wise to attempt to use the same design schedule for machines of different kinds. It seems to me we lose as much as we gain. We gain because the printer has to set up only one form; but we surely lose because when we try to design induction motors, rotary converters, alternators, and continuous-current machines with the same data-lines and the same little pictures, we are apt to be cramped. It seems to me it would be far better to take each type of machine and find what is the best way of laying out the schedule for designing it, and then print a schedule for machines of that particular type.

Mr. A. R. EVEREST: This very interesting paper appears to divide itself into four parts: (1) A plea for uniformity in methods of calculating the principal characteristics

Professor  
Thompson.

Mr.  
Everest.

Mr. Everest.

of electrical machinery; (2) a discussion of the relative merits of employing maximum air-gap density as against the total pole-flux as the basis of the machine calculation; (3) a plea for the use of a universal calculation sheet to cover various types of machines; and (4) a very interesting discussion of the methods of calculating the principal characteristics. As regards the first point, a greater uniformity of method in treatment is certainly desirable, but I am afraid difficult of attainment until those professors and others who train our men and provide our textbooks and other technical literature have taken some steps towards uniformity of method. An engineer wishing to look up the latest investigations on a certain subject will consult not only the writings of Dr. Silvanus Thompson and Professor Miles Walker, but also those of Dr. Steinmetz in America, and Boucherot in France, as well as other Continental writers. The methods of these investigators are so diverse that in order properly to grasp the argument it is often necessary first to re-translate into a system more familiar to the inquirer. On this account much valuable information of which the engineer would be glad to avail himself is not utilized as it might be. I am afraid the idea of getting anything like a universal system of treatment is out of the question, but there does not seem to be any good reason why symbols used should differ as much as they now do amongst different writers. Passing to the third item, the plea for use of a universal calculation sheet covering various types of machines, I agree with Dr. Thompson that the advisability of this appears doubtful from the point of view of the design office. Each particular class of machine has certain characteristics which are of essential importance and need to be studied in particular detail, and we should therefore like to devote more space on our calculation sheet to those particular characteristics. Also the universal "picture" of the pole and slot arrangement is not so convenient as one more nearly corresponding to the particular type of machine under consideration. There are certain fundamental principles which should be carried out in all these calculation sheets: the essential characteristics of the machine ought to appear prominently so that when criticizing and comparing designs these points can be picked out readily; but more than that, the make-up of the characteristics should, in my opinion, appear in the form of an equation containing the values taken for the different factors involved, as it is often desirable on reconsideration to modify one or more of these factors. On this account I do not like the use of one coefficient embodying several different factors, as I understand the author suggests. Turning now to the second point, it is suggested that the maximum air-gap density should be taken as the reference characteristic. I must admit a preference for the use of the total pole-flux as the basis of design, and for a density figure it seems preferable to use the mean density taken over the entire pole-pitch. This value being a real quantity is more useful in making comparisons on the basis of the output coefficient. Regarding the author's remarks in connection with cooling and the more effective value of narrow ducts, I should like to suggest that the cooling value of the duct is really determined by the ratio of surface to cross-section. Time does not permit of discussion of the interesting material in the Appendixes, but it will repay careful

study and no doubt some valuable new ideas can be derived therefrom.

Mr. Burgess.

Mr. H. BURGESS: Those who design electrical machines are still occasionally worried by a specification in which the engineer sets a limit to the current density in the armature and in the field winding. Curiously enough, in this paper, written by one who is admittedly a high authority, one finds no reference to current density in connection with the prediction of temperature rise of a machine. Of course the temperature rise has really nothing to do with the current density; it depends merely on the ventilation and on how the conductors are massed together. Turning to the main proposal of the paper, namely, to reduce the E.M.F. formula to one general form for all kinds of machines, I think there is a good deal to be said for it, but the arguments on page 246 in favour of it are, I think, somewhat doubtful. For instance, the author says the designer can keep in his mind the value of this magnetic loading ( $A_p/B$ ) for any particular frame, and, moreover, that it is independent of the number of poles. As far as continuous-current machines are concerned, however, in dealing with a standard line of frames, every frame has a fixed number of poles; consequently, every particular frame always has the same flux per pole. It seems to me that the flux per pole in that case is just as easy to memorize as the total magnetic loading. Again, in arriving at the tooth density the author refers to the difficulty of estimating the exact number of teeth lying under a pole. This difficulty is due to the bevelling of the pole-tips, and it seems to me that the coefficient  $K_f$  depends on the very same thing, so I do not think that argument applies. Reference is made on page 260 to the leakage of induction motors. In my opinion the total number of slots chosen does not play a sufficiently prominent part in the author's formula. It is true that it is represented in the zig-zag leakage by the slot pitch, but the zig-zag leakage only appears to be about one-quarter of the total, and I think a machine with a very few slots would actually show a very much poorer performance than this formula would suggest. In conclusion I should like to add my appreciation of this very serviceable paper.

Mr. C. C. HAWKINS: Upon the general subject of the paper I am in agreement with the author in thinking that almost all classes of electrical machinery can be designed on very similar lines, and that it would be an advantage to employ a common design sheet, or sheets which are at least based on the same system of design, simply from the facility which one acquires from repeated use of the same form and the ease with which the designer can pass from one class of machine to another. I am not, however, convinced that a comparison of the various quantities on the design sheets for radically different types of machines is of much value. As Mr. Everest has already pointed out, each type has its own laws and must be designed in accordance with those laws. Still this need not forbid the use of a common design sheet. The first part of the paper is really a plea for the retention of the maximum value of  $B_z$  in an expression for the fundamental E.M.F. equation which is based on the total flux, and I think that the author has advanced strong grounds for retaining this maximum value, one important reason being the ease with which the maximum flux density in the teeth can be calculated. I am, however, surprised to find that the value of the

maximum flux density in the air-gap, upon the importance of which stress is laid, is finally lost sight of in the joint product  $A_p B$ . It may be that in the factory, with particular frames in use, the value of  $B_p$  is kept clearly in mind and is to be found in the body of the design sheets, but it seems a pity that it should not be more clearly retained at the head of the design sheet as a separate quantity. Mr. Burge mentioned the fact that in a given frame  $A_p B$  is not really independent of the number of poles, but I think all that the author means is that over a wide range of sizes and number of poles the economical value to which  $B_p$  can be pushed is fairly constant. When plotting the flux curve in the case of a large 2-pole turbo-alternator in which not merely the rotor teeth but also the rotor core is highly saturated, it becomes worth while to introduce a further refinement on the method given in the paper. After the preliminary flux curve of Fig. 4 has been plotted, which is based on a consideration of the ampere-turns expended over the radial portions of the flux paths through the rotor teeth and air-gaps, an approximate estimate of the gradual accumulation of the flux in the rotor core towards the centre of the exciting coil can be made, and thence can be calculated the ampere-turns required over each tooth-pitch along the circumferential portions of the paths. For example, suppose that it is found that 400 ampere-turns are required to pass the flux through the rotor core from the centre of the exciting coil to the solid pole-centre and back through the stator core; then, of this amount, successive tooth-pitches reckoning from the centre will absorb, say, 100, 77, 60, and so on in diminishing amount. The effective radial ampere-turns (using the winding of Fig. 4) are then  $1,710 - 100 = 1,610$  acting on tooth 1;  $3,420 - 177 = 3,243$  acting on tooth 2; and so on. The flux curve can thus be corrected to a greater degree of accuracy. When this process is carried out, it will be found that the initial part of the flux curve is slightly concave, and that a point of inflexion occurs when the diminution in the saturation of the rotor core exactly balances the increasing saturation of the rotor teeth; after this point the tooth effect predominates and the curve becomes convex as shown in Fig. 4. Of course, this effect will only be noticeable in the case of machines with highly saturated rotor cores, and it may be asked whether experimental proof can be obtained from oscillograms. The answer is that the effect is masked partly by the presence of ripples due to the teeth, and still more by the fact that so far no account has been taken of the slot flux or transverse component of the actually existing flux. The third stage in the predetermination of the shape of the flux curve requires a most careful estimate of the amount of the slot flux and of its influence on the main radial flux—a subject which is too complex to consider here at length. I would, however, advocate that we should in general speak of slot flux rather than of slot leakage, since flux traversing a slot may in certain cases be very useful, as enabling the lines to avoid highly saturated portions. A case in point is afforded by the flux which passes between a solid pole-centre and the upper parts of the adjacent teeth on either side, so avoiding the highly saturated roots of these teeth. Such flux plays the same part as the steel wedge to which the author has alluded.

Dr. S. P. SMITH: I am very pleased that the author makes the suggestion that we should arrive at some

common method of designing electric machines; and I Dr. Smith, for one should be very glad if such a method could be found, even if all of us had to make some compromise from our pet methods. Indeed, for my own part, I am sorry the author put any more into the paper than the description of his proposed method, not because I do not appreciate fully the value of the appendixes, but because I think the author's proposal that there should be a discussion on design methods ought to be carried out in its entirety. I was pleased to hear Professor Thompson refer to Esson's work and tell us how the output coefficient was first made known at an Institution meeting. It is interesting to learn that his result was obtained empirically. Starting from first principles to deduce Esson's expression for the output of an electric machine gives us at once the relation between the two methods referred to by the author. The mechanical force  $F$  exerted on a conductor of length  $L$  centimetres lying perpendicularly to a field of density  $B$  and carrying a current of  $I$  amperes is

$$F = B I L \times 10^{-7} \text{ dynes} \quad (1)$$

Taking the simple case of a continuous-current machine, where there are  $N$  conductors each carrying  $I_a$  amperes and moving in a field of mean density  $B_{\text{mean}}$ , then

$$F = B_{\text{mean}} N I_a L \times 10^{-7} \text{ dynes} \quad (2)$$

An exactly similar form of expression is obtained for all other heteropolar types when the laws followed by  $B$  and  $I$  are inserted in Equation (1). In Equation (2),  $B_{\text{mean}}$  = (flux per pole)  $\div$  (area of pole-pitch). This is the actual mean density in the gap, as used by Mr. Everest, and does not contain a constant for the polar arc, as given by Professor Thompson. Then for the mechanical power

$$\begin{aligned} P &= F v = F \cdot \pi D n / 60 \\ &= B_{\text{mean}} \cdot N I_a \cdot L \cdot 10^{-7} \times \pi D n / 60 \text{ ergs per sec.} \\ &= (\pi D L B_{\text{mean}}) (N I_a) (n / 60) 10^{-8} \text{ watts} \quad (3) \\ &= (K_f A B_{\text{max}}) (N I_a) (n / 60) 10^{-8} \text{ watts} \quad (4) \end{aligned}$$

Equation (3) shows how the output depends on the product of the total magnetic loading  $\pi D L B_{\text{mean}} = A B_{\text{mean}}$  and the total electric loading  $N I_a$ . Equation (4) gives the form advocated by the author in order to introduce the maximum value of the flux density, where  $K_f B_{\text{max}} = B_{\text{mean}}$ . Here again  $K_f A B_{\text{max}}$  is a total quantity, whilst  $B_{\text{max}}$  is absorbed in the product. For the alternative expression we substitute, in Equation (3),  $\pi D a c$  for  $N I_a$ , where  $a c$  = ampere-conductors per centimetre of the periphery, so that

$$P = (\pi^2 / 60) D^2 L n B_{\text{mean}} a c \times 10^{-8} \text{ watts} \quad (5)$$

The output is now seen to depend on  $D^2 L$ ,  $B_{\text{mean}}$ , and  $a c$ . The latter quantities can be called the specific magnetic and electric loadings. There is no need to develop this further, because  $P$  [or  $P / (D^2 L n)$ ] can be similarly found with its proper constant for any type. The question now arises: which is the better form, Equation (4) or Equation (5)? Obviously  $B_{\text{max}}$  can be introduced into Equation (5) in the same way as in Equation (4), but the difference is not whether we shall use  $B_{\text{mean}}$  or  $B_{\text{max}}$ , but whether we shall use total quantities or specific quantities. Whether we use  $B_{\text{max}}$ , or  $B_{\text{mean}}$  is largely a matter of taste, for even

if the former is more useful in calculating certain parts, the latter is more fundamental in the output equation. But the difference between total and specific loadings is very important, because, generally speaking, total quantities convey no precise meaning. Thus if we are told that a beam supports a load of 20 tons, we are not able to appreciate what this means until we know the material and cross-section of the beam; but given these we can at once calculate the stresses and strains—specific quantities. Or again, to be told that a current of 10 amperes flows along a wire conveys little to the engineer; but a knowledge of the cross-section and material enables us to see at once how the wire is rated. Is not this the reason why we have weights and measures? In electric machines,  $ac$  is not affected by the material, since copper alters very little, but  $B_{max}$  may be largely influenced by the quality and treatment of the iron. Thus with a knowledge of the permissible limits of the specific quantities  $B_{max}$  and  $ac$ , the design of any type of machine can be carried out from first principles and the main dimensions determined: whereas the total quantities  $AB_{max}$  and  $NI_a$  have only meaning when the frame size is given. Hence, whilst Equation (5) may be said to be general for teaching or designing, Equation (4) is really an office method suitable for standard lines.

Mr. H. ROTTENBURG: This paper is particularly opportune at the present time when so many are trying to improve our national efficiency. Unfortunately the ideal towards which the author strives to help us, namely the standardization of methods of design, is made more inaccessible through the want of standardization of symbols, as one speaker has already pointed out. Two other speakers, by using different symbols from those employed by the author, have shown us, I think, that the gaps between the ideals of different designers seem less difficult to surmount mentally than the gaps between different sets of symbols. They are certainly very much less illogical. Could not the Institution arrange to collect from all the teachers of electrical engineering, authors of textbooks and papers, etc., a list of the symbols they use, and publish these in parallel columns? Such a publication would form a most useful dictionary for translating from one system of symbols into another, and would also bring home to us all the absurdity of this scientific Tower of Babel. There is another suggestion I should like to make which many may consider very trivial, but which would do some good at very little cost, namely, that numbers which enter into any paper should be printed in heavy type the first time they occur in the paper. It would often save us the trouble of looking back to see whether a number had entered into a previous equation or formula. In regard to the predetermination of the characteristics of continuous-current generators, I have found the following construction both simple and useful, especially in teaching, as it shows very clearly the way the different factors enter into the final result. The magnetization curve is drawn with a scale of volts as ordinates and field amperes as abscissae, the latter scale having its zero at the origin and extending in both directions. From O, the origin, a line OA is laid off with a scale of armature current on it such that the ordinate and abscissa of any point on it give the armature drop in volts and demagnetization effect in terms of field amperes, due to the armature current represented by the point. To find

the terminal volts associated with any given armature current, a point  $A_1$  is taken on OA giving the required armature current, and through this point a horizontal line and a line making an angle of  $\tan^{-1}$  (shunt-field resistance) with the horizontal. If this latter line cuts the magnetizing curve in  $P_1$ ,  $P_1$ , then the ordinates  $P_1N_1$  and  $P_1N_1'$  from  $P_1$ ,  $P_1$  to the horizontal through  $A_1$ , will give the terminal pressures. The dotted lines in Fig. A show the construc-

Mr.  
Rottenburg.

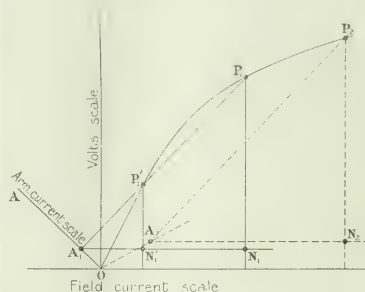


FIG. A.

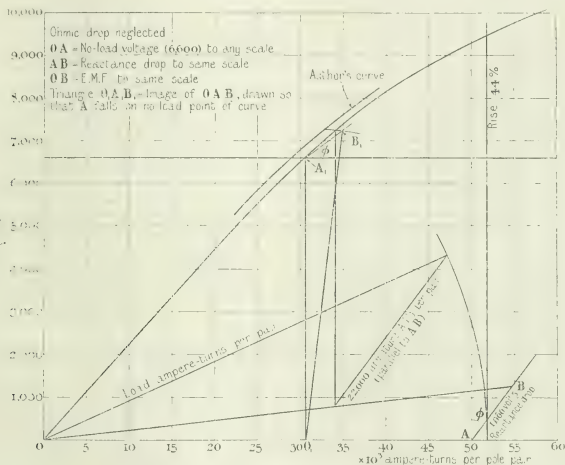
tion for a compound generator. The points on OA, in this case give as ordinates the armature plus series-field drop, and as abscissae the compounding effect minus the armature demagnetizing effect, both measured in terms of field amperes. In regard to the very interesting remarks by Dr. Thompson on Esson's formula, it would be interesting to compare this with the formula for output in terms of fundamental dimensions derived for the petrol engine by Mr. Lanchester in a paper read before the Institute of Automobile Engineers in 1906-7 on "Horse-power of the Petrol Motor in relation to Bore, Stroke, and Weight." In this paper the dimensional formula for output is given as  $L^2$ . Mr. Lanchester drew attention to the widespread application of this and mentioned the case of the output of animals, which was limited by the area of their lung surface and in a similar way by the cross-section of the aorta. In a burning mass of fuel the output varied as the area of the incandescent surface of the fuel. In the case of a generator, the output as limited by heating would seem to be limited by the area of the cooling surface. If this area law is applicable to generators in general, it should be possible to transform Esson's formula in such a way that it shows the same fundamental dimensions.

Mr. B. A. M. BOYCE (communicated): The method put forward by the author is most interesting and has many good points. I should like, however, to draw attention to a few points that, in my opinion, make the proposed universal method dangerous in a design office. In the first place it is usual in most design offices for one man to specialize on one class of work, though it is advisable for every man to understudy his colleagues. Now, as time is very important, I consider that each man should use a form giving all the data for his class of work, so that the

form is completely filled in and there are no blanks. When that man refers to forms of other machines, there is no chance of his obtaining wrong figures or constants as in the case of the universal form. At the Brush Company we use a 3-sheet alternator form, a 3-sheet continuous-current form, and a 1-sheet induction-motor form. With regard to the universal form when used for alternators, I should like to see: (1) kw. as well as k.v.a. at the head. This would reduce the chance of an error such as that on page 250 under "Efficiency," where output is stated as 2,430 kw. instead of 2,160 kw., thus giving incorrect efficiencies. (2) Losses and efficiencies at unity power as well as at the specified power factor. (3) Resistances

circuit power factor. I do not see the advantage of the system proposed over the methods generally employed, since (flux per pole)  $\times$  (No. of poles) gives the magnetic loading, and  $I_a Z_a$  the current loading. Fig. B shows a magnetization curve of the alternator on page 250 worked out on the flux-per-pole method. This is done by calculating two magnetization curves, one for the small tooth and the other for the large tooth, i.e. the unwound pole face, plotting flux against ampere-turns. Now for any number of ampere-turns the flux can be read off from these curves and a series of fluxes obtained, which when added together give the total flux, whereby we calculate the voltage from those ampere-turns. It will be noticed that this curve

Mr. Boyce.



Mr. Boyce

necessary to make an allowance on the calculated figure. We do not agree with the author that the reactance-drop has very little effect on the excitation required, particularly in single-phase machines and machines with high saturation. On the magnetization curve is set out a graphical method of obtaining the full-load excitation, which is simple and gives good results. My attention was first drawn to this method by Dr. S. P. Smith. The method of Mr. H. D. Symons and the author for calculating temperature-rises has been used by us ever since that paper was published, and with excellent results, as it enables the designer to follow the heat paths step by step. The following expression gives a rough check on the temperature of a turbo-alternator rotor:—

$$a = \frac{I \cdot R}{S \cdot 1 + 0.1 \sqrt{V}}; T = \frac{C a}{1 - C a / 250}$$

where I = current in rotor;

R = rotor resistance (cold);

S = barrel surface of rotor + barrel surface of end caps in sq. cm.;

V = velocity in metres per second;

T = temperature rise in degrees C., by resistance;

C = 200.

Professor Walker.

Professor MILES BURGESS (in reply): I am in agreement with what Dr. Thompson says about the D<sup>2</sup>L formula; I was in fact brought up on his books and most of my ideas on dynamo design are founded on the fundamental formulæ so clearly stated by him. The formulæ in the paper are not put forward as at all original, but merely as a statement of one method by which we can calculate all dynamo-electric machines in the same way. It is not necessary to insist upon the use of a single printed form; I have tried to show that one method of calculation can be used for all machines, and I emphasized the fact by using the same printed form for each; but, as several speakers have pointed out, it may be convenient to amplify the calculation for some particular class of machines to such an extent that one would be compelled to utilize another page or two. That can still be done, although we adhere in the main to the one method of calculation. Anyone who has worked in a large electrical engineering office and seen how many methods of calculation are employed and how little one member of the staff knows of the method of another member, will see the desirability of some kind of codification of methods. That codification need not in any way hinder the originality of any engineer, any more than his originality would be hindered by presenting him with a die-press that will do for any class of machine. To suggest a common method by which to simplify design in no way deprives designers of other methods which are of use to them. Mr. Everest has pointed out the disadvantages which arise through our teachers and writers using so many different methods. It is quite possible that in course of time a wider agreement upon a simple system will lighten the work of our students.

I will reply to those members who are of opinion that it is better to write down the mean value of B in the fundamental formula of the dynamo than to write down the maximum value of B. In the first place, one should note that the expression  $K_f B$  gives the mean value of B, so that

we retain all the advantages of having the mean B before us, and at the same time we comply with what Mr. Everest advocated, namely, the retention of each important quantity as a separate term, rather than the combining of several factors in one symbol. It must be admitted that the maximum B is an exceedingly useful quantity to have before us; it appears (this in reply to Mr. Hawkins) on the calculation sheet under the heading "Magnetization curve." Dr. Smith thinks that we ought to keep to specific quantities. Now the mean B is not a specific quantity—it is a mental abstraction. The specific loading on any particular part of the machine is B; every part of the armature has to pass through the point of maximum B. If we multiply by  $K_f$ , we find the effectiveness of B in producing an electromotive force, having regard to the field-form, the coil width, etc. Next as regards the product  $A_s B$ ; this is objected to by some speakers as being a hypothetical quantity. That statement in itself would not be an argument against its use, because almost every formula contains symbols which if taken in pairs separately would represent hypothetical quantities. Looking at it as a quantity which affects the cost of the frame,  $A_s B$  is very analogous to many quantities used by engineers. It is necessary to give only one example: Consider a steel I-beam of a certain length, required to support a certain load. The section having been settled, the quantity which the engineer has to pay for is a certain weight of metal multiplied by the price of steel having a certain maximum tensile strength. The mean stress in the beam does not matter; the maximum stress settles the price of the beam.  $A_s$  is analogous to the quantity of steel;  $B_{\max}$  is analogous to the maximum stress. If we find the value of  $\psi$  by means of the simple construction described by Dr. Thompson, then the B in his formula is the maximum B and we are in agreement again.

In reply to Mr. Burge, it should be pointed out that the method of finding  $K_f$  for a machine with a bevelled pole is a perfectly straightforward and precise process which can be carried out rapidly when occasion arises. In most cases  $K_f$  is known for the pole in question. The estimating of the number of teeth per pole is a matter upon which two designers can easily differ. The number of slots per pole of an induction motor plays a more important part in the formulæ given for the leakage than Mr. Burge may have noticed. The leakage per pole is made a function of the current per slot, and this changes with the number of slots per pole.

Mr. Hawkins is quite right in what he says about the slot flux greatly affecting the field-form when the teeth are very highly saturated. The rounding-off of the top of the field-form is due to the augmentation of the flux from the most highly saturated teeth by flux entering them from the sides.

The formulæ given by Dr. Smith, based on the force exerted in a conductor, show several aspects of the matter which are of great importance to the student and to the designer, and the method of deducing them is simple and striking. Still I prefer to replace  $B_{\text{mean}}$  in formula (5) by  $K_f B_{\max}$ .

The additional items which Mr. Boyce would add to the calculation sheet are all useful and certainly could be added with advantage. The supposed error in calculation is not an error at all. A machine of the kind under

Professor Walker.

consideration is usually sold to deliver its k.v.a. rating at any power factor from unity down to some specified figure (in this case 0.8). It is not often in a large power station that one has the power factor as low as 0.8. In fact 0.9 is a much more likely figure, so that in giving guarantees of efficiency a manufacturer prefers to give guarantees based on 0.9 power factor, rather than the more exceptional condition of 0.8 which is not so favourable to him. It would, I agree, be good to have room on

the form to work out the efficiency at a number of different power factors.

I am in agreement with Mr. Rottenburg that we must make a greater effort to get our symbols into better order.

Finally, I must thank the British Westinghouse Company for permission to publish some of the data given, and also Mr. B. G. Lamme for first showing me the outline of the method of design advocated in the paper.

Professor  
Walker

## A SET OF PROPOSED STANDARD NUMERALS FOR THE SCALES OF MEASURING INSTRUMENTS.

By A. P. TROTTER, Member.

(Paper received 11 January, 1916.)

[These notes were originally prepared in 1908. In 1915, at the request of the Meter Panel of the Engineering Standards Committee on Electrical Accessories, they were placed at their disposal, and at their suggestion are now published.]

At about the beginning of this century a reform in typography was initiated by Emery Walker, Cobden Sanderson, Douglas Cockerell, Bernard Newdigate, and Edward Johnston, followers of William Morris, all artists as well as craftsmen. They aimed at the production of beautiful printing and formal writing, but the special use of numerals for the scales of measuring instruments was naturally not within their province. This use differs from the typography of numerals which occur in ordinary printed matter or in tables. Edward Johnson in his admirable book on writing dismisses "Arabic numerals" in three

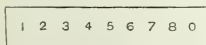


FIG. 1.—Colonel A. Strange's numeral figures, supplied by Messrs. W. F. Stanley & Co.

lines with the suggestion that "1 and 0 may be made on the line, 2, 4, 6, 8 ascending, and 3, 5, 7, 9 descending." In the very clear type of Barlow's Tables and of this *Journal*, 6 and 8 rise above the general level, and 3, 4, 5, 7, and 9 extend below the base line, but such excursions are not suitable for use on scales.

In about the year 1870, my uncle, the late Colonel A. Strange, F.R.S., Director of the Trigonometrical Survey of India, and afterwards Inspector of Scientific Supplies for the Stores Department of the India Office, designed a set of standard numeral figures. They were probably badly needed. I have been unable to obtain a copy of his figures on a large scale, but Messrs. W. F. Stanley & Company have kindly sent me specimens on ivory from punches made to these figures (Fig. 1), and I am indebted to the Stores Department of the India Office for a set (Fig. 2) differing slightly from the former, but probably another version of Colonel Strange's design. I will allude to these as the India Office figures. I have carefully measured up these two sets of figures with a microscope, and the principal dimensions are given in a table below.

After examining the numerals used on a large number of measuring instruments, including electricity meters, surveyor's staffs, and the Admiralty standard scales, I

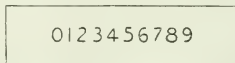


FIG. 2.—Numeral figures supplied by the Stores Department of the India Office.

designed a set in 1908 with the sole view of legibility (Fig. 3). Elegance of shape was not disregarded altogether, but wherever necessary it was sacrificed to legibility.

Except, perhaps, in the case of the 1, there should be no serifs, the figures should be of the block character, that is to say, there should be no marked difference in the thick-

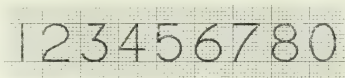


FIG. 3.—Numerals designed by A. P. Trotter. Minimum Thickness.

ness of the line in any part of the figure. The thickness is either sufficient or it is not. The conventional changes of thickness originated in pen writing. I have not designed each numeral separately, but the relations between the 3, the 5, and the 8, and between the 6, or the 9, and 0 were considered with the object of preventing confusion.

The first proportion to be settled is the ratio of the height to the width of the containing rectangle, and the next is the ratio of the height of the figure to the width of the line which forms it. Certain letters of the Roman alphabet in the inscriptions of the finest period, and amongst these the O, are contained in a square. It appears that with a height of 10 units legibility begins to suffer if

the width is materially less than 7 units; a greater width is a waste of space.

The thickness of the line should not be less than one-twentieth of the height of the figure, that is, half a unit, nor thicker than  $1\frac{1}{2}$  units. Colonel Strange seems to have adopted about 0.86 unit. In the following descriptions and in Fig. 3 the minimum width of half a unit has been adopted, and dimensions refer to over-all measurements.

o. The o should be an ellipse, the height being 10; Colonel Strange used a width of 7.6. A width of 7 seems to be sufficient, though 7.5 would perhaps look better.

1. If any serif is used it should be a very small one, to avoid confusion with 7.

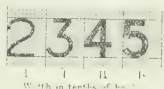


FIG. 4.—Numerals—designed by A. P. Trotter, Various Thicknesses.

2. The India Office 2 is not graceful. Colonel Strange's 2 is 7.2 units wide. I think that the proposed standard width of 7 units may be adopted. The upper part of the figure should be half of an ellipse, semi-minor axis 3. The breast of the figure rises from the lower bar with an arc of radius 5 and joins the upper part by an easy curve. For the sake of legibility the curve at the lower part of the breast is much better than a straight line making an acute angle with the bottom bar.

3. A serious defect in Colonel Strange's 3 is that it is practically an 8 with a small bit cut out. The India Office 3 seems unnecessarily narrow. In designing this figure care must be taken to avoid confusion with 5 as well as with 8. For this reason I strongly recommend the flat-

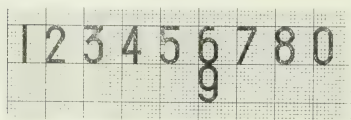


FIG. 5.—Admiralty pattern numerals.

topped 3. To emphasize the difference from 5, I think the upper part should be set back a little to the right, at some loss of gracefulness. A bar 5 units long joined by a line sloping at 60° to the lower part, which consists of about three-quarters of an ellipse; major axis 7, minor axis 6. The limb curving up to the left, after rising 2 units, is cut off square.

4. The 4 with the stem united to the sloping line is commonly used, the disunited form being a script character. The horizontal bar of the India Office 4 seems unnecessarily low. This height in Colonel Strange's 4 is 3.5 units. I recommend that with a line 1 unit thick the lower side of the bar should be 3 units from the base line. If the bar is higher the appearance is spoiled. Colonel

Strange's width is about 7.1, which agrees well with my proposed 7 units. The bar should overhang to the right 2 units. This gives a slope of 3 in 2 for the slanting line.

5. Colonel Strange's 5 is excellent. The line joining the bar with the lower part is not quite vertical. This slight slope adds considerably to the appearance of the figure, and I think that a slope of  $\frac{1}{4}$  unit in 5 may be given, but any more would tend to confusion with the 3. I recommend that the lower part of the 5 should consist of about three-quarters of a circle of outside diameter 7. The nearly vertical line should be brought well forward to distinguish it from the 3, even if the general appearance suffers somewhat. The top bar may be 5.5 units long.

6. I cannot recommend Colonel Strange's 6. It is liable to confusion with 8 and with o. I propose that the lower part should be an ellipse, width 7, height 6; and the upper part an arc of 7 units radius, struck from the end of the major axis of the ellipse. This type of 6 is generally used for figures in which tails above or below the general limits are permitted. In such cases a 6 or 9 is often merely an o with a tail.

According to the usual practice, the 9 is simply the 6 reversed.

7. For uniformity with the other figures the top bar should be 7 units wide. To improve the appearance the down stroke should have a slight curvature, say 30 units radius. Colonel Strange uses a curve but the India Office version, a straight line.

8. According to the usual convention of the design of the letters B and S, the 8 consists of two slightly unequal parts. An extremely small difference is easily perceptible and adds a good deal to the appearance, as in a well-formed B. I propose a major axis of 6 for the upper part, and a minor axis 5; the minor axis of the lower part is 6, making the middle of the common line 5.5 units above the base.

#### Dimensions of Numerals.

All reduced to height = 10.

	India Office	Col. A. Strange	Proposed
Width of line ...	0.8 to 1.7	0.86	1
2. Width of, ...	4.5	7.2	7
Semi-ellipse major axis ...	—	—	7
" minor " ...	—	—	3
Radius of breast ...	—	—	5
3. Width of top ...	4.5	6.9	5
Ellipse major axis ...	—	—	7
" minor " ...	—	—	6
4. Width of, ...	8.0	7.1	7
Centre of bar from base ...	2.8	3.5	3.5
Overhang of tail from centre of stem ...	3.0	2.15	2.5
5. Width of, ...	6.5	7.8	7
Down stroke, over all ...	4.0	5.3	5
Width of top bar ...	4.0	6.0	5.5
6. Width of, ...	6.5	7.8	7
Ellipse major axis ...	—	—	7
" minor " ...	—	—	6
Radius of tail ...	—	—	7
7. Width of, ...	5.5	8.6	7
Radius of tail ...	—	—	3.0
8. Width of lower part ...	8.0	8.6	7
" upper " ...	6.3	7.8	6
Centre of cross bar from base ...	5.5	5.7	5.5
o. Width of, ...	7.4	7.6	7

## HYDRO-ELECTRIC POWER IN NEW ZEALAND.

By W. WILSON, B.E., M.Sc., Associate Member.

*(Paper first received 22 October, 1915, and in final form 7 January, 1916)*

## INTRODUCTION.

This paper is intended to describe the possibilities of the Dominion of New Zealand with regard to the provision of power from natural hydraulic resources; and also to present a brief summary of the development that has already been carried out, with the conditions under which this has been done, the means adopted for taking advantage of them, and opportunities for the future.

New Zealand is remarkable for its abundant possession of available water power. In Table I a list of sources of natural energy is given, in all of which the development is devoid of serious difficulty, the total horse-power represented being 3,650,000. In addition to this, there are numerous smaller sources of less than 1,000 h.p. each which have not been included. As will be shown later, however, these latter are by no means negligible, and many are fulfilling a decided demand in various parts of the Dominion.

Owing to the very diverse nature of the country, practically all varieties of falls are met with, from the mountain torrent of the Southern Alps, to the lakes and fiords of the extreme South, where very great supplies of energy can be tapped at low cost. Although these larger schemes have up to the present proved too remote from closely inhabited districts for their fulfilment to have been advisable, yet the low cost of their development, combined with the productiveness of the country, and the excellent deep-water access to the sites, hold out bright prospects for the near future.

An additional feature of interest is the enterprise of the Dominion Government, which, without closing the way to private development, is carrying out a comprehensive scheme of its own for providing electricity to residents and industries throughout the country.

The subject will be treated in the following order:—

- Description of the country.
- Early enterprise.
- Varieties of water-power schemes.
- Water power available.
- The Government and water-power development.
- Water power in present use.
- Description of existing stations.
- Schemes for the future.
- Utilization of power.
- Conclusion.

## DESCRIPTION OF THE COUNTRY.

New Zealand is an isolated country lying in almost exactly the antipodes of Great Britain. It consists principally of two islands, called the North and the South Island respectively, and has a total area of 104,750 square miles, or about one-seventh less than that of Great Britain

and Ireland. It is for the most part a narrow land, approximately 1,100 miles in length and 94 miles in average width. Extending between the southern latitudes of 34° and 48°, it forms a southern counterpart to Japan in its chief physical characteristics, although its institutions and people, numbering just over a million, are pronouncedly British.

The North Island is slightly the smaller of the two, and the more irregular in outline. With the exception of several volcanic peaks such as Egmont (8,250 ft.), Ruapehu (9,150 ft.), and Tongariro (6,458 ft.), the frequent mountain chains rise to heights seldom exceeding 5,000 ft.

The South Island is nowhere wider than 180 miles, while throughout its whole length a backbone of peaks and ranges, known as the Southern Alps, raises the interior to a height of as much as 10,000 to 12,000 ft.

Thus it will be seen that the conditions throughout the country strongly favour frequent changes in the land-level and an abundant rainfall, averaging 51·34 inches annually in the North Island and 46·63 inches in the South. All species of streams, from broad, steady-flowing rivers to alpine cataracts, abound throughout both islands; and more valuable still, the numerous large basins and depressions, formed by the geological action so evident everywhere, have provided sites for a great number of lakes, mostly in elevated positions within easy reach of lower country. Hence New Zealand presents exceptional opportunities for the engineer.

## EARLY ENTERPRISE.

It is interesting to record that the first example of a hydro-electric transmission scheme in New Zealand, and one of the first anywhere, belonged to the part that has just been referred to. It was not long after the colonization of the country, which, it should be noted, only took place about 1840, that water power was applied to the direct driving of mills and similar plants in places where these were favourably situated. One such existed at the Phoenix Gold Mine, Skipper's Creek, in the Lake Wakatipu district, where, early in the eighties, a Liffel turbine was used to drive the 30-stamp battery forming part of the equipment.

The water supply for this, however, was intermittent, and steam power was added to carry on during dry periods. Coal was supplied by pack-horse at a cost of about £6 per ton, and, as can be easily realized, it was employed as sparingly as possible. A much more abundant and a constant supply of water was available in another branch of the creek, but its use at the battery would have involved about 5 miles of aqueduct through country so difficult as to put this expedient quite out of the question.

In 1886, however, Mr. R. E. Fletcher, advised the use of electricity for solving the problem, and the

plant that he designed provides an example of the difficulties such pioneers had to overcome, both from the isolation of the locality and from the comparative crudity of the appliances then extant. At that time, also, very few projects at all comparable with this one were in existence.

By means of an open race 1 mile in length, a fall of 160 feet was obtained at a vertical cliff, down which two wrought-iron pipes conveyed the water to the power house at the foot. In it, two 6-ft. Pelton wheels were belted to Brush series-wound "forty-lighters," giving 10 amperes at 2,000 volts. These were connected in parallel, with cross-connected fields, and fed a  $\frac{3}{4}$ -mile transmission line consisting of two No. 8 copper wires and passing over very rough and precipitous country. It should be remembered that all plant and materials had to be conveyed over a long distance of similar country on the backs of pack-horses.

The motor was a Brush 6-pole Mordey-Victoria series machine, requiring 20 amperes at 1,600 volts and 1,200 r.p.m. Connected in series with it was an iron-wire rheostat capable of absorbing continuously the full output of the generators. The motor was started and regulated by cutting out or inserting varying amounts of this resistance.

As a matter of fact this motor, probably the first to be constructed for anything like so high a voltage, was found wanting, partly through inadequate insulation and partly through flashing-over at the commutator, which latter was only 8 in. in diameter, with no more than 16 segments between the brushes of opposite polarity. The difficulty was satisfactorily overcome by halving the potential. First, the armature and field-magnet coils of each generator were connected in parallel-series to give half the voltage and double the current. Then the motor was rewound in situ for 800 volts and 40 amperes. This operation, carried out among the rugged mountains of a distant colony, would not be a simple matter to-day; 30 years ago, when 50 or 100 was the normal voltage, it must have demanded no little courage and skill. At all events, the trouble was cured, and the plant gave every satisfaction during the 12 years that completed the life of the mine.

Another plant was installed by the same engineer in 1890 to operate a gold dredge on the Shotover River, not very far from the same locality. It should be explained that these apparatus, so much employed in New Zealand where the rivers in some districts constitute natural sluice-boxes for finely divided gold, require two main supplies of power—one for the ladder of buckets which raise the sand from the bed of the river, and the other for the centrifugal pump which washes away the lighter constituents, leaving the metal behind.

In this case four similar machines were connected in series, two being generators in the power house about three miles distant, and two being motors, driving these two pieces of equipment respectively. Each was a 4-pole Mordey-Victoria series dynamo, wound for 850 volts and 40 amperes, so that the transmission voltage was 1,700.

The generators were belt-driven by a 4-ft. Pelton wheel, ungoverned. Fluctuations of current were checked by the pump motor, which, by absorbing surplus power, acted as a regulator. A break in the line was provided against by an automatic switch, which inserted a resistance if the line current fell below a given value.

Like its sister-plant, this one also worked with complete success until the claim was exhausted, when all was dismantled. It is unfortunate that such examples of successful enterprise should perforce have had but a brief existence, and should not have been the forerunners of permanent schemes. However, in addition to carrying out all the functions required of them, they served the purpose of demonstrating to the rest of New Zealand the possibilities and advantages of hydro-electric power.

#### VARIETIES OF WATER-POWER SCHEMES.

The most numerous potential power sites, and generally those involving the least expense in development, occur among the mountains of both islands, where there is a myriad of large and small cataracts and waterfalls; these are most numerous in the Southern Alps of the South Island, although the peaks of the North, such as Egmont and Te Aroha, are supplying communities with electricity to-day. The first considerable plant in the Dominion, that at the Waipori Falls which transmits current to Dunedin, and the Holt's Creek and Punchbowl stations generating for the Otira Tunnel in the middle of the Island, are Southern examples. As is usually the case with this type of scheme, the best conditions have a way of occurring in hardly accessible situations, and the water supply is not very constant. Storage is not as a rule easy to provide, owing to the movement of shingle during floods.

It is therefore from the big rivers and the lakes of the lower country that most power is at present being drawn, and these afford the greatest possibilities for the future. Large rivers are frequent, and as a rule fall rapidly. Nearly all pass through narrow gorges before emerging from the mountainous country, and have their courses intersected by reefs, as at the Hora Hora Rapids utilized by the Waihi Gold Mining Company. Lakes are especially plentiful near the borders of the ranges in the South Island, and among the uplands in the heart of the North. In many cases a direct fall is obtained by simple tunnelling, as at Lakes Kanieri and Coleridge. In other cases they act as nearly perfect storage reservoirs for the rivers flowing from or through them, as in the case of Lake Taupo and the Waikato River (in the course of which occur the Hora Hora Rapids), and of Lakes Rotorua and Rotoiti and the Kaituna (which includes the Okere Falls).

Lastly, the extreme south-west of the colony possesses a long stretch of coast-line indented with deep fiords. These are in reality submerged valleys which have been scooped wider in late geological history by extensive glacier action. Tributary valleys are thus cut back, and form "hanging" stream-beds, from which many waterfalls flow into these arms of the sea. A host of lakes also occur within a few miles of the water fronts. Add to these circumstances a rainfall estimated to provide 2,000 b.h.p. per mile of drainage area, and we have conditions almost unparalleled in the world for the cheap generation of power, closely resembling, in fact, those in the favoured portions of Norway. At present the country surrounding the fiords is more picturesque than useful, forming one of the principal tourist resorts of this part of the world. Apart from scattered accommodation for the visiting public and a few mining settlements, it is practically uninhabited, and so far little development has been undertaken in this region.



FIG. 2.

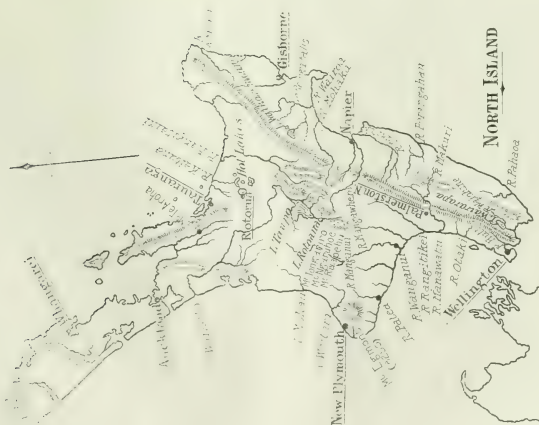


FIG. 1.

## POWER AVAILABLE.

The late Mr. P. S. Hay, Superintending Engineer of the New Zealand Government Public Works Department, issued, as a result of much patient investigation, comprehensive reports on the hydro-electric resources of the Dominion in 1904 and 1905. In these, the most easily available schemes were described in detail, the total production thus dealt with being estimated at 3,700,000 h.p., measured at the turbine shafts, for continuous working. In these estimates, the efficiency of the water-wheels was assumed to be 80 per cent, and losses in races and pipes

were allowed for. On the supposition that 60 per cent of the brake horse-power developed was paid for at the rate of £12 per brake horse-power per annum, all these schemes will pay at least 4 per cent on first cost, plus renewals, sinking fund, cost of staff, and management. The work has been carried on by Mr. Hay's successors, Messrs. R. W. Holmes, and Mr. Evan Parry, the present Dominion electrical engineer.

The following table, derived from the current Government Year Book, gives the most recently compiled information on this subject:—

TABLE I.  
Most Important Sources of Water Power exceeding 1,000 h.p.

Source of Power	Position of Power House	Available Flow, ft. per sec.	Available Head, ft.	Available Power		Nearest City, Port, or Deep Water	Distance in Miles
				h.p.	kw.		
NORTH ISLAND.							
North Auckland District							
Wairua Falls ... ..	Wairua Falls	300	130	3,200	2,400	Whangarei	16
South Auckland District							
Kaituna ... ..	Okere Falls	800	784	52,000	39,000	{Tauranga	25
Waikato River ... ..	Huka Falls	6,000	67	33,000	25,000	{Auckland	125
" " " " " "	Aratiatia Rapids	6,000	100	50,000	37,000	{Auckland	158
" " " " " "	Orakeikorako Rapids	6,000	35	17,500	13,000	"	158
" " " " " "	Aniwhaniwha Falls	6,000	80	40,000	30,000	"	148
" " " " " "	Atiamuri Rapids	6,000	25	12,500	9,300	"	142
" " " " " "	Hora Hora Rapids	6,000	28	14,000	10,500	{Auckland	130
						{Waihi	97
							47
Hawkes Bay District							
Waikaremoana ... ..	Waikaretaheki	1,100	1,420	133,000	10,000	{Gisborne	65
						{Napier	75
						{Wellington	280
Waikareiti ... ..	Waikaremoana	180	700	10,500	8,200	{Gisborne	75
						{Wellington	290
Te Reinga Falls ... ..	Te Reinga Falls	600	125	6,200	4,700	{Gisborne	35
						{Napier	70
Wanganui District							
Lake Rotoaira ... ..	River Patu	260	520	11,000	8,500	Wanganui	105
Mangawhero River ... ..	Ruakawa Falls	300	220	5,500	4,100	"	45
" " " " " "	Wanganui River	300	900	22,500	17,000	{Wanganui	24
						{Palmerston N.	60
Manganui ... ..	" "	—	700	10,000	7,500	{Wanganui	65
Rangitikei River ... ..	Vinegar Hill	1,500	400	50,000	37,500	{Wanganui	48
						{Wellington	142
Taranaki District							
Waitara River ... ..	Waitara River	800	30	2,000	1,500	New Plymouth	35
Wellington District							
Mangahai River ... ..	Tokomaru	115	1,050	10,000	7,500	{Palmerston N.	16
						{Wellington	76
Tokomaru River ... ..	"	100	440	4,000	3,000	{Palmerston N.	16
						{Wellington	76
Makuri River ... ..	Makuri Gorge	100	384	3,200	2,400	{Palmerston N.	28
						{Wellington	107
Waiohine River ... ..	Woodside	200	400	6,600	5,000	{Masterton	20
Otaki River ... ..	Otaki	—	—	4,000	3,000	{Wellington	51
Tauherenikau River ... ..	Featherston	150	440	5,500	4,200	"	47
Hutu River ... ..	Mungaroa	300	305	9,900	6,800	"	46
						"	25
(North Island) Total horse-power				495,600			

Source of Power	Position of Power House	Available Flow, ft. per sec.	Available Head, ft.	Available Power		Nearest City, Port, or Deep Water	Distance in Miles
				h.p.	k.w.		
SOUTH ISLAND.							
Nelson District							
Boulder Lake ...	Aorere River	50	2,600	11,000	8,000	Golden Bay	10
Rotoiti Lake ...	Gowan River	200	1,200	20,000	15,000	Westport	48
Rotorua Lake ...	Buller River	900	400	30,000	22,000	Nelson	48
Buller River ...	Lyell	—	—	25,000	18,000	Westport	24
Inangahua River ...	Blackwater River	780	125	8,000	6,000	"	18
Westland District							
Lake Brunner ...	Stillwater	1,750	200	20,000	22,000	Greymouth	10
Kumara Water-race ...	Kumara	87	330	2,400	1,800	"	12
Otira River ...	Otira	40	700	2,300	1,700	"	52
Rolleston River ...	"	36	700	2,000	1,500	"	52
Kanieri Lake ...	Kanieri River	100	330	2,800	2,100	Hokitika	20
Toaroa River ...	Toaroa River	300	760	10,000	14,300	"	17
Whitcombe River ...	Hokitika River	250	800	16,000	12,000	"	20
Kakapohia River ...	Kakapohia River	100	580	4,800	3,600	"	26
Wanganui River ...	Hende's Ferry	830	580	40,000	30,000	"	36
Wataroa River ...	Wataroa	1,360	700	80,000	60,000	"	48
Canterbury District							
Clarence River ...	Jollie's Pass	200	1,160	20,000	15,000	Christchurch	82
" " ...	Conway River	1,150	1,050	100,000	75,000	Christchurch	88
Waiaua River ...	Culverden	1,600	200	27,000	20,000	Kaikoura	25
Waimakariri River ...	Gorge Bridge	2,000	160	27,000	20,000	Christchurch	75
Lake Coleridge ...	Rakaia River	200	480	8,000	6,000	"	30
Acheron River ...	"	50	480	2,000	1,500	"	70
Harper River ...	"	420	480	16,800	12,600	"	70
Wilberforce River ...	"	1,100	480	44,000	33,000	"	70
Rakaia River ...	Gorge Bridge	1,600	30	6,500	4,800	"	52
Lake Heron ...	Rakaia River	300	200	4,000	3,000	"	88
Rangitata River ...	Arundel	1,100	250	23,000	17,000	Timaru	35
Opihi River ...	Opihi Gorge	200	400	6,700	5,000	"	30
Opuha River ...	"	200	400	6,700	5,000	Christchurch	100
Tekapo Lake ...	Fairlie	5,100	900	400,000	300,000	Timaru	40
Ohau Lake ...	Waitaki River	5,000	600	250,000	180,000	"	52
Otago and Southland Districts							
Ahuriri River ...	Waitaki River	600	200	10,000	7,500	Oamaru	62
Waipori Falls ...	Waipori River	135	650	7,300	5,500	Timaru	100
Lee Stream ...	Outram	15	750	1,280	970	Dunedin	19
Deep Stream ...	Taieri River	110	900	8,400	6,300	"	20
Taieri River ...	Deep Stream	700	220	12,000	9,000	"	44
Talla Burn ...	Clutha River	30	890	2,200	1,600	"	60
Teviot River ...	Roxburgh	200	1,900	32,000	24,000	"	90
Mauwhera River ...	Chatto Creek	200	350	5,800	4,400	"	60
Hawea Lake ...	Wanaka Lake	3,600	220	66,000	50,000	"	127
Wakatipu Lake ...	Kawarau River	11,000	544	500,500	375,000	"	140
Shotover ...	Wakatipu Lake	500	250	14,000	11,000	Invercargill	112
Lake Hall ...	Doubtful Sound	220	2,625	48,000	36,000	On Seaboard	—
Lake Cecil ...	Lake Te Anau	200	900	15,000	11,200	"	—
Lake Hilda ...	"	1,550	1,190	50,000	41,000	"	—
Lake Te Anau ...	Gorge Sound	12,630	604	750,000	500,000	"	—
Lake Manapouri ...	Smith Sound	8,400	600	420,000	315,000	"	—
Lake Monowai ...	Lake Hauroto	700	410	24,000	18,000	Invercargill	60
Lake Hauroto ...	Tewahae Bay	2,300	514	100,000	75,000	"	51

(South Island) Total horse-power 3,305,480

Total horse-power for Dominion... 3,801,080

These sites are arranged in geographical order, from north to south, and from west to east. Their positions may be made out upon the maps (Figs. 1 and 2).

#### HISTORY OF THE GOVERNMENT CONNECTION WITH WATER-POWER DEVELOPMENT.

At the present date the attitude of the Government towards the development of these hydro-electric resources under its control is most satisfactory. According to the Public Works Act of 1908, the sole right to use the water-power of the Dominion is vested in His Majesty the King, any existing rights excepted. The Government is

existed, their predecessors adopting the extremes, first of over-generosity, and then of almost complete obstruction. Towards the beginning of the present century, a private company applied for rights to use the energy latent in the Waipori Falls, some 30 miles from the City of Dunedin. This request was granted without any payment. Not long afterwards the City Corporation wished to take over the project, and purchased from the Company the water rights which had been acquired for nothing. The effect of this transaction upon the authorities was such that they adopted the opposite policy of not parting with their water assets for any reasonable consideration. Thus the rush of hydro-



FIG. 3.

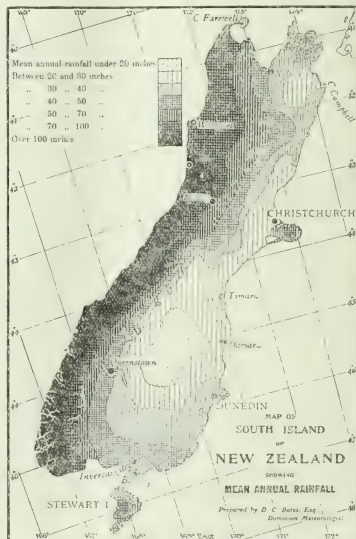


FIG. 4.

empowered either to prosecute the work itself, or to delegate its power to a local authority or private concern, subject to stated conditions. These conditions the present Ministry are interpreting wisely and progressively. Not only are they themselves carrying out a general scheme of providing hydraulically-generated electricity all over the country, but they are permitting municipalities and other local authorities to utilize water resources free of any royalty. Companies and private persons can obtain the privilege, subject to a payment of 1/20d. per unit generated.

Unfortunately, until the present Government assumed office in 1911, this favourable state of things by no means

electric activity which promised to follow the initial success at Waipori was seriously checked.

As a substitute for private enterprise, a Bill was formulated in 1910 whereby a sum of £2,000,000 to £2,500,000 was to be expended upon eight schemes distributed through the Dominion at the places enumerated in Table 2.

It was proposed to make an immediate start with Nos. 1, 4, and 5. The current from all was to be retailed on a basis of 2d. per unit for light, and 1d. for power. The whole scheme was to be complete in four or five years, thus involving an expenditure of half a million pounds per annum.

However, this extensive programme was not proceeded

with. Instead, it was decided to complete No. 5, which was considered the most promising enterprise, first, and to use the experience so gained for carrying out the others. At the end of four years the plant mentioned was in operation, but in the meantime the Liberal Government, which had held office continuously for 21 years, was replaced by one whose announced intention was to afford much greater facilities for the use of water power.

TABLE 2.

Locality	District	Horse-power	Cost
(1) Wairua Falls...	North Auckland	3,000	100,000
(2) River Kaituna	South Auckland	10,000	320,000
(3) Makuri Gorge	North Wellington	6,000	200,000
(4) River Hutt ...	South Wellington	10,000	300,000
(5) Lake Coleridge	Canterbury	10,000	270,000
(6) Kumara ...	Westland	3,000	75,000
(7) Teviot... ..	Otago	10,000	300,000
(8) Lake Hauroro	Southland	10,000	350,000

At once a private company purchased for £150 per annum the rights to the Wairua Falls, No. 1 on the above list, and their station is fast approaching completion. Other enterprise has taken place on smaller schemes, and is foreshadowed on a larger scale in the near future, though the rapid improvement of the lignite gas-producer has assisted the institution of small local power houses at the expense of the hydraulic central station.

#### WATER POWER IN PRESENT USE.

Table 3 gives the uses to which water power was put on the 31st July, 1914.

It will be seen that the generation of electricity absorbs the great bulk of the power made use of. Of the 26,000 h.p. so employed, nearly 12,000 h.p. was on the date given

distributed for public use (see Table 4), though during the past year the figures have been much increased. Thirteen stations, under various managements, were employed.

TABLE 3.

#### Uses of Water Power in New Zealand.

Electricity supply ... ..	25,849 h.p.
Mining ... ..	3,150 "
Freezing works ... ..	1,200 "
Dairying ... ..	783 "
Construction work ... ..	721 "
Flax-milling ... ..	511 "
Paper-milling ... ..	465 "
Flour-milling... ..	412 "
Saw-milling ... ..	262 "
Other uses ... ..	1,454 "
Total ... ..	34,816 h.p.

The principal addition to Table 4 since it was compiled is the Lake Coleridge station, constructed and operated by the Government, of a present capacity of 6,000 h.p. and 4,500 kw. The current is transmitted 70 miles at 66,000 volts.

Besides these stations for public supply, there are a number of others owned by private companies, chiefly mining syndicates, and used for industrial purposes. One of these, indeed, is at the present time the largest power plant in the Dominion. This is the station of the Waihi Gold Mining Company at Hora Hora, of 9,000 kw. The Ross Gold Mining Company have one of 1,000 h.p. at Lake Kanieri, the Earnscleugh Company one on the Fraser River of 700 h.p. for operating their gold dredge, and there are others of less importance.

#### EXISTING STATIONS.

Under this heading is given a short description of the chief stations already in operation.

TABLE 4.

#### Particulars of Public Electricity Stations (1914).

Locality	Supply Authority	Population Served	Power, h.p.	Installed kw.	Distance Transmitted, miles	Transmission Voltage
Rotorua ... ..	Government	2,360	380	200	13	6,600
Dunedin ... ..	Municipality	64,237	9,000	6,000	32	35,000
New Plymouth ... ..	"	5,238	1,020	680	5	2,000
Te Aroha ... ..	"	1,298	255	150	3	3,000
Inglewood ... ..	"	1,273	200	120	—	3,200
Taihape ... ..	"	1,577	133	100	2	460
Patea ... ..	"	919	60	45	4	3,000
Mangaweka ... ..	"	1,800	47	35	3	2,400
Akaroa ... ..	"	622	45	20	1	220
Hawera ... ..	Company	2,685	400	250	12	5,000
Stratford ... ..	"	2,639	150	90	2	2,000
Reefton ... ..	"	1,500	80	60	1	230
Brightwater ... ..	Private individual	800	53	40	4	2,500
Total horse-power		...	...	11,823		

(From New Zealand Year Book, 1914.)

## (1) WAIPOI FALLS.

To the City of Dunedin belongs the credit of having first employed natural resources on a large scale for the generation of electricity. Prior to the year 1900, very little use indeed had been made of water power anywhere in the Dominion, and a few plants of small capacity represented all the advantage hitherto derived from it. But about that year the Dunedin Corporation projected a small scheme upon the Lee Stream, and took certain steps in the direction of carrying it out. While they were hesitating, the Waipori Falls Company was formed for developing an initial supply of 2,000 kw. in a narrow gorge some 32 miles in straight-line distance from the city. Events progressed favourably, and the work of construction was begun and was considerably advanced under the auspices of the Company.

During this time the Council had been reconsidering their own scheme, and finally entered into negotiations with the Company, with the result that they took over the whole plant. Included in the purchase money was the sum of £10,000 for water rights, the payment already referred to as having shocked the Government into an attitude of "passive resistance" as far as water power was concerned.

Owing to the change in the management and to other delays, it was not till towards the middle of 1907 that the current was finally switched on to the new converters and transformers, which were erected for its reception in the old tramway power-house, henceforth the distributing station. The current was well taken up from the start, and it was found necessary to duplicate the generating plant in 1910, and to triplicate it three years later. Further additions are in contemplation.

The Waipori River is a very typical New Zealand mountain cataract, and the difficulties encountered are those commonly met with in this type of scheme. The water falls 520 ft. from the head of the ravine, where a simple masonry dam was constructed, to the powerhouse at the foot, and  $1\frac{1}{2}$  miles of wooden fluming, 6 ft. wide and 2 ft. deep, was constructed round the winding hill-side to the forebay. Unfortunately, this timber work was lying idle for years pending the completion of the work, and not long after taking up its function it showed signs of weakness. Its position on the side of the gorge rendered it liable to damage from slips, except at two places where it tunneled through spurs, and after some trouble from these causes it was entirely superseded by a complete tunnel through the rock.

The flow of water is by no means uniform, and a particularly dry February just before the scheme opened drew attention to this failing. Storage was difficult, chiefly on account of the shingle drift at flood time, but in spite of this, lakes have been formed at three places above the falls, advantage being taken of tributary valleys for this purpose. A Diesel-engine stand-by station has also been erected in the city.

Like many other similar buildings in the Dominion, the power station is constructed of ferro-concrete. In such a locality shingle is abundant, and excellent Portland cement is available from a number of factories in both islands. Inside the building are six 1,000-kw. units by the General Electric Company of America, each con-

sisting of a 2,400-volt 3-phase generator, driven by a tangential water-wheel on either extremity of the armature shaft. The standard frequency of 50 per second is employed, obtained at a speed of 500 revs. per minute, regulated by Lombard governors. Deflecting nozzles were fitted to the first four units, but when storage was adopted and economy of water was possible, spear-valve throttling was adopted for future machinery. About 20 miles separates the Falls from the sub-station just outside Dunedin. The current was transformed to 20,000 volts and star-connections employed, giving 34,700 volts for transmission. The poles are of Australian hardwood, 35 ft. long, and spaced 150 ft. apart. Duplicate lines traverse opposite sides of the same route, and the wires are of copper. With regard to the immunity of the district from severe lightning conditions, it is interesting to note that out of 5,500 high-tension porcelain insulators, less than 2 per cent have been renewed after eight years.

A few notes as to the finance of this, the oldest hydro-electric scheme in New Zealand, may be of interest. Up to the 31st March, 1915, the capital cost was £483,952. For the past 12 months the revenue was £57,627, and the running costs £18,799. After providing for interest (£20,997), depreciation (£3,825), and renewal fund (£10,145), there was a net profit of £3,860. The generation and distribution costs were:—

	Pence per unit sold	
	1915	1914
Fuel ... ..	0'0027	0'0148
Oil, etc. ... ..	0'0011	0'0009
Wages ... ..	0'233	0'269
Repairs, etc. ... ..	0'0499	0'0457
Public lighting (works cost) ... ..	0'287	0'3305
Rents ... ..	0'114	0'1238
Total costs ... ..	0'402	0'4543
(exclusive of public lighting)		

Current for lighting is sold at 5d. and 1d. on the maximum-demand system, the average price being 3'35d. per unit; and energy for power is sold at from 2d. to as low as  $\frac{1}{2}$ d. per unit, the average price being 0'739d.

## (2) LAKE COLERIDGE.

An almost complete contrast to the foregoing is exhibited by the first of the big Government schemes to reach completion. That at Lake Coleridge was selected as the first installation to be carried into effect because of the outstanding simplicity and comparative cheapness of the work entailed, its moderate distance (70 miles) from the city of Christchurch (a town of 86,000 inhabitants), the great storage capacity existing, and the opportunities for numerous extensions in the future. For years the citizens of Christchurch had been vainly endeavouring to secure water rights for themselves, and the evident demand promised well for the sale of the current.

The lake itself is a body of water 13'8 square miles in extent, with a drainage area of 86 square miles. Although surrounded by mountains of as much as 7,000 ft. in height, the outflow is comparatively small, averaging about 160 cubic feet per second. Its situation just within the fringe of the Southern Alps seems to be one sheltered by the main range from the direct moisture-bearing winds of the

western ocean. Still, the water at present available is more than sufficient to maintain a load of 10,000 kw. on a load factor of 50 per cent; but, when desired, water can be diverted into the lake at very little expense from two more streams, the Harper and the Acheron (see Fig. 5), giving an additional flow of 650 cubic feet per second. The addition of the Wilberforce, a stream with double the flow of all the other sources added together, is also possible.

In the distant past the lake formed part of a big river, the Rakaia, which was dammed by glacial debris and diverted into a valley parallel with its original course. Between the two bodies of water there now exists a head of 490 ft. gross, and a horizontal distance, at the locality selected for the pipe-line, of 1 mile 64 chains. It only needed a short tunnel, therefore, to connect the pipe-line

power house; and two 4 ft. 4 in. steel pipe-lines, 2,460 ft. in length, conduct the water thither. Sluice-gates are provided for four such pipes altogether, and the remaining two will in all probability soon be requisitioned.

Originally, the power plant was designed to consist of six 1,500-h.p. Francis turbines, of which three by Escher-Wyss are already working, and a fourth is being installed. The remaining two units, however, will be of 3,000 h.p. each. Bruce-Peebles 3-phase alternators are direct-coupled to these wheels, giving 6,600 volts at 50 cycles and 500 revs. per min. Six single-phase General Electric (U.S.A.) water-cooled transformers are used at each end of the line. These step the voltage up to 66,000 volts for transmission, and then down to 11,000 volts, star connections being adopted at the secondaries of the receiving end. The generating plant is housed in a flat-roofed station,

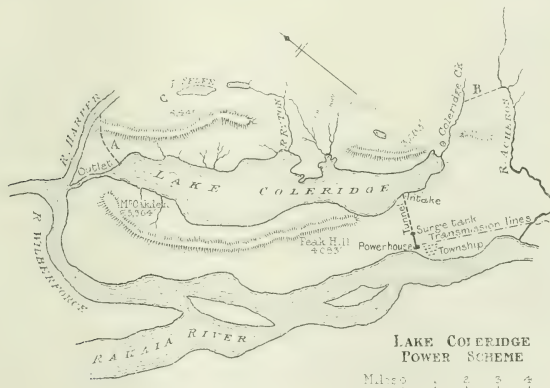


FIG 5.

directly with the waters of the lake, which could be run off as required without the necessity of an expensive dam or headworks.

In nearly every respect the practical conditions at Lake Coleridge are ideal. Notwithstanding its altitude of 1,770 ft., the water has never been known to freeze, largely on account of its great depth, which in places reaches 700 ft. There is no floating or other debris, and the only problem in connection with the intake consisted in dealing with the shingle moved by the high winds that occasionally blow down the lake from the north-west. The intake is exposed to this drift, and a roughly semicircular groin has been built in the form of a breakwater round the entrance to the tunnel, which is 20 ft. below the normal water-level. A reduction of 1 ft. in height will give a flow of 100 cubic feet per second for 47 days.

The tunnel is 106 chains in length, and its semi-elliptical cross-section has an area of 50 square feet. On the river side of the hill it ends in a concrete surge-tank above the

again of ferro-concrete, the construction of which cost 8½d. per cubic foot. It should be explained that a total distance of 32 miles separates the power house from Coalgate, the little country village affording the nearest railway access, and the 15,000 tons of goods involved in the complete work were transported by as many as 13 traction engines.

Transmission is effected by six 7/0·135 aluminium cables, arranged on duplicate lines pursuing distinct routes, except for a short distance in the valley near the power house. Ironbark poles are used, 42 ft. in total length, set 6 ft. in the ground, and separated by the wide spacing of 6 chains. Though fairly high winds are occasionally experienced, they blow along the direction of the line. No rigorously low temperatures are experienced, and during the cold weather high winds are wanting, so that in designing the line to resist both conditions simultaneously, the engineers have provided ample latitude for all contingencies.

The insulators are of the pin type, and are of porcelain,

weighing 28 lb. each. A few interruptions have been caused by the failure of these, in all probability, chiefly on account of the tempting mark they offer for "sportsmen" armed with guns or more primitive missiles.

It is expected that the whole scheme of 16,000 h.p., including transmission lines to all the main centres of population in the Canterbury province, will be completed at a cost of £375,000. The power is being retailed direct to factories and similar large consumers; the butter factory at Tai Tapu, for example, is not only itself changing over completely to electric drive, but is undertaking the reticulation of the neighbourhood, and the distribution of electricity as its own speculation. Christchurch city is supplied by contract at the rate of £8 13s. 4d. per annum per kilowatt of maximum demand for the first 300 kw., and £5 per annum for every kilowatt above this amount.

1,214 ft., and the Waikato, in its course from the lake to Cambridge, passes over the six considerable falls enumerated in Table 1.

As will be observed, none of them has a head of more than 100 ft., and the last, and therefore the most accessible, is that at Hora Hora, with a total fall of 28 ft. At this particular point the bed is intersected by beds of rock, causing a diversion of the course, accompanied by two main cataracts, all within a straight-line distance of 24 chains. By the simple expedient of cutting a straight canal, 100 ft. wide at the bottom, to short-circuit the rapids, and projecting an inexpensive crib-work dam into the river, a remarkably straightforward and reliable scheme for generating 9,000 kw. has been brought about. The canal is partly cut through soft rock, which required no lining, and partly through shingle, which was lined with

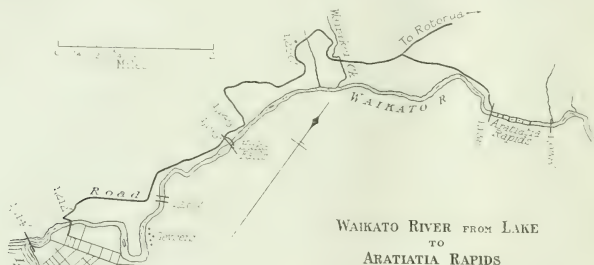


FIG. 6.

This power is delivered by conduit at 11,000 volts at the Council's sub-station in the centre of the town, while the power house of the Tramway Board, in another quarter, is supplied under a separate agreement.

### (3) HORA HORA RAPIDS (WAIKATO RIVER).

The Waikato River affords a further variety of scheme, in that it derives its energy from the Hora Hora Rapids, about 18 miles from Cambridge, which is 100 miles by rail south-east of Auckland. This stream is the longest in the Dominion, and carries the greatest volume of water of any in the North Island. From its 5,600 square miles of drainage area it derives an average of 9,000 cubic feet of water per second, the minimum being 6,500 cubic feet. This is its volume as it issues from Lake Taupo, which, in its turn, is New Zealand's largest lake. It has an area of 238 square miles, and is interesting as occupying the hollow left by a huge subsidence following upon volcanic action. The slight variation in the outflow referred to is its only possible defect as a reservoir. This is caused by an occasional high wind, which heaps the water upon the opposite shore. If necessary the effect could be minimized by the installation of a regulating dam. Situated near the centre of the island, Lake Taupo has an elevation of

concrete, costing only 2s. 9d. per cubic yard plus the cost of the cement.

Ferro-concrete was again the material of the power house, which contains the six Siemens 1,500-kw. 3-phase alternators and switchgear. Boving turbines, in quadruple sets, are located in forebays external to the building, while the transformers are in a separate sub-station higher up on the terraced bank of the river.

The main object of the scheme was to provide the mines and batteries of the Waihi Gold Mining Company, about 50 miles distant, with power, though the Company have undertaken to supply any towns in the vicinity that desire it. Under the circumstances, a single transmission line was considered sufficient, and this has been made as reliable as possible, with lattice-steel towers and copper conductors. Three-phase current is generated at 5,000 volts, and stepped up to 50,000 volts in single-phase transformers.

Owing largely to the falling-off in production of the Waihi field just after the scheme was undertaken, there is a great deal of power to spare. Unfortunately, the terms and conditions formulated by the Company have not been proving acceptable to the neighbouring boroughs, and none of them have so far availed themselves of their

opportunities to purchase. The Company are paying £1,200 per annum for the water rights.

The existing turbines use a maximum of only 4,000 cubic feet per second, so that an extension of at least 60 per cent is possible on the spot. When more power is required in this district, similar schemes, mostly on a much larger scale, can be brought into existence at the other localities mentioned earlier, to the extent of at least 153,000 h.p.

(4) OKERE FALLS (KAITUNA RIVER).

Some 50 miles north-eastward of Taupo occur a remarkable group of lakes of similar origin to the former, which are commonly known as the "Hot Lakes," from the thermal activity evident in the form of geysers, mud volcanoes, and hot springs in the vicinity. Two of these, Rotorua and Rototoi, are drained by the Kaituna River, which flows through an extremely narrow gorge on its way to the sea (19 miles distant in a straight line), falling 904 ft. as it does so. A small local scheme is at work near the entrance to this gorge; but its chief importance is derived from the fact that the site is the most favourable for the supply of Auckland city, a project that would involve a transmission of 120 miles. This, in fact, is Scheme No. 2 of the Water Power Act in Table 2.

Lake Rotorua has an area of  $31\frac{1}{2}$  square miles, and discharges through the Ohau Channel into Rototoi, which requires to be at a lower level by 2 ft. in order that the requisite flow may take place. The latter lake is only 1375 square miles in area; and the Kaituna River is not far from the connecting channel. Altogether, the two lakes have a drainage area of 248 square miles, resulting in an average outflow of at least 800 cubic feet per second.

The present Okere Falls station was erected about 11 years ago, to operate the pumping station and lighting of Rotorua township, a tourist and health resort administered by the Government. It is a completely equipped and generally excellent plant, but with peculiar caution it has been given a capacity of only 250 kw, and is at a point not far down the river from the lake, where a head of only 14 ft. is available. Consequently, during most of its career it has proved too small for the local demand.

In so narrow a gorge, cut in solid rock, damming was not a serious matter, and a concrete weir has been constructed right across the opening. A wooden flume takes off sufficient water at one side of this, and conducts it a short distance down the gorge as far as the foot of this particular rapid. Here a site for the power house was cut out of the rock. Samson and Waverley pressure turbines are enclosed in steel drums in the station itself, with shafts horizontal. B.T.H. generators are driven from them by chain-leather belts, giving 3-phase current at 6,000 volts and 50 cycles.

For the larger scheme, several alternatives have been proposed, according to the amount of head to be utilized by the one plant. Three such alternatives were mentioned by the late Mr. Hay in one of his reports, of which particulars are given in Table 5.

There is an additional fall of about 400 ft. in the next 9 miles. In all probability the conduit will be taken as far as the ground will carry it, and the first power house located at that point. If the utmost development is effected, it may be possible to obtain 80,000 or 90,000 h.p. One great advantage possessed by all these projects

TABLE 5.

	Scheme A	Scheme B	Scheme C
Distance below lake ...	62 chains	2 miles	3 miles
Head ... ..	101 ft.	177 ft.	325 ft.
Horse-power generated...	8,800	16,200	31,600
Horse-power delivered ...	5,280	9,720	18,960
Cost ... ..	£340,000	£550,000	£880,000
Estimated revenue ...	£31,689	£58,380	£113,760

over those on the Waikato is that the justly prized scenic assets of the Dominion are interfered with only to a very slight extent.

(5) WAIRUA SCHEME.

Project No. 1 of the Government proposals in Table 2 might almost be described as an existing scheme, as its construction has been in hand for some time, and it would have been completed before now but for delay caused by high floods at a critical part of the work. The Wairua is a lowland river with a drainage area of 266 square miles, but with no natural storage. A variable rainfall causes rather

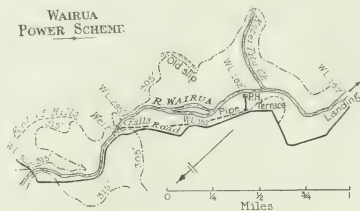


FIG. 7.

violent fluctuations in the flow, which averages about 500 cubic feet per second, the minimum being about 200 cubic feet; but, fortunately, good opportunities for damming occur, and shingle is quite absent. The Dominion Portland Cement Company are carrying out the work, initially to provide power for their new mill on the shores of Whangarei harbour, 16 miles distant. They have also contracted to supply the town of Whangarei, five miles further on, Dargaville, a large town in the opposite direction, and the vicinity generally.

There is about  $2\frac{1}{2}$  miles of water-course, mostly gorge, between the falls and the boat landing at the head of the navigable portion of the stream. The waterfall itself has a drop of 46 ft., but is followed by cataracts which increase the total to 141 ft. Practically the whole of this fall is being utilized by means of a weir immediately above the falls, and  $1\frac{1}{2}$  miles of race, partly cut in rock and partly concreted. The storage dam is situated higher up the river, and though only 84 ft. in height it will conserve

sufficient water to work the plant for three weeks, irrespective of any assistance from the river. In addition, there are excellent facilities for further storage when necessary.

For the present, two Boving turbines are being installed to give 1,350 h.p. each; but the company intend to duplicate the plant in the near future. Practically all the electrical gear is by the General Electric Company (U.S.A.). The power house is of ferro-concrete, and the transmission lines of aluminium. When complete, the whole installation should cost £50,000.

#### (6) LAKE KANIERI.

Another power development for mining purposes occurs near the west coast of the South Island, and is interesting as exemplifying the different conditions in this region from those of the somewhat similar scheme at Lake Coleridge on the eastern side of the main watershed. This lake has an area of 56 square miles, but being in much more broken country has a drainage area of only 16 square miles. On the other hand the rainfall is 120 in. per annum, about three times that at Coleridge. An effective head of 250 ft. is obtained by cutting an 8-mile race, over two miles of which is in tunnel. Only 700 h.p. is developed in the present scheme, chiefly for unwatering the mine of the Ross Goldfields Company. Probably from 3,000 to 5,000 h.p. could be obtained if necessary. The level of the lake can easily be raised 25 ft., giving ample storage.

The present transmission line is 23 miles long, and operates at 24,000 volts. A non-standard frequency of 60 has for some reason been adopted here.

#### (7) MOUNTAIN SCHEMES, OTIRA TUNNEL.

About midway in the length of the Southern Alps, a long tunnel of nearly  $5\frac{1}{2}$  miles is being pierced to afford railway connection between east and west. Electricity is needed here for two purposes: at present for the work of excavation and construction; and in the future, for railway traction. For the former, two schemes are in operation and well exemplify the conditions under which an alpine scheme is required to work. For main-line traction a more abundant supply of power will be necessary, and this will be derived either from Lake Coleridge, about 50 miles away, or from one or more fair-sized rivers near the western portal.

For the preliminary supply, two falls were harnessed very close to the extremities of the tunnel. On the western side of the great watershed, Holt's Creek has been utilized, a cataract in the mountain side falling steeply into the Rolleston Gorge, in the side of which the tunnel has been pierced. On the east, the Devil's Punchbowl has been employed, a waterfall flowing over the edge of a precipice 790 ft. high. Both operate identical power plants, consisting of two 290-kw. tangential-wheel sets in each case, by Messrs. J. P. Hall, working at a head of 700 ft. and generating continuous current at 550 volts.

At the head of Holt's Creek there are two falls which enter the ravine through narrow passages in the rock. The lower (and larger) fall was worked first. A short concrete dam was constructed across the opening, after a short tunnel had been drilled to take the water from the

basin. The 18-in. wooden pipes pass through this tunnel, and proceed down the gully for about a third of the total distance. They are then joined to more robust pipes of riveted steel. Wherever possible, they have been located on the side of the ravine in order to be well out of the way of the flood-water. For a greater part of the length a ledge was cut in the rock for the reception of the pipe-line, and a trestle bridge and two girder bridges, all of timber, support it where this is difficult and where it has been necessary to cross the stream. No expansion joints are used. Some months after the power house had been running on the larger fall, the water from the smaller one



FIG. 8.

was brought into the basin above the former by means of a wooden flume, led round a vertical rock face and supported by a trestle construction.

For the Punchbowl, more tunnelling and less pipe-line were required, there being not much more than half a mile of the latter. The water has carved for itself a deep cleft in the hill, and the tunnel provides an exit through the side of this gap to the more gentle slope of the main valley.

Both plants are subject to occasional shortages, chiefly in winter, when the sources partially freeze. Most importance attaches to the work at the western, or downhill end, and here a stand-by steam plant of 150 kw. has been installed. Storage is out of the question

for such plants, and would be almost impossible in any case, especially at Holt's Creek.

It is convenient to refer here to the project for increasing the power supply after the railway is complete. Down the gorge on the western slope of Arthur's Pass, beneath which the tunnel makes its way, flows the Otira River. After emerging from its gorge, in which it falls 1,400 ft. in about two miles, the Rolleston enters in a tributary gorge, the confluence being about  $\frac{3}{4}$  mile below the mouth of the tunnel. Between the two gorges the mountain side tapers into a spur, the top of which is over 500 ft. above the river bed at the tunnel entrance.

Some distance up the Otira Gorge, the river flows through a narrow gap, not more than 40 ft. in width, with sides of hard rock. It is somewhat higher than the top of the spur mentioned above; if, therefore, a weir were built across this opening, and a drive of about 7,000 ft. in length made to conduct the water to the top of this spur, a quantity of water could be stored in a reservoir cut in the substance of the hill, ready to generate energy when required for taking a train up the tunnel. By a curious coincidence, a similar rocky gap exists at the same elevation in the Rolleston Gorge, and requires only 1,000 ft. more drive than in the case of the Otira. Thus, if necessary, two supplies of water could be delivered at a point over the mouth of the tunnel, from which only about 1,000 ft. of pipes would be required to attain a net head of 500 ft.

Now about 2,000 h.p. would be required to take an average train up the 1 in 33 grade of the tunnel, and for this a continuous flow of 50 cubic feet per second would be necessary. Suitable storage, however, would reduce the water required to about half this amount. Gauging the Otira after a five days' frost gave over 60 cubic feet per second for the Otira, and 39 cubic feet for the Rolleston. If the water flowing in the boulders beneath the bed of the stream could be measured, these amounts would probably be substantially increased. Thus it will be seen that, although these streams are occasionally somewhat smaller than the figures quoted, there is plenty of water for the work. It is also practicable to draw off the water at a higher point, where a head of nearly 1,200 ft. can be obtained. By doing so, 6,000 h.p. could be developed, and much more by bringing in the Bealey River from the other side of the watershed.

#### SCHEMES FOR THE FUTURE.

In the above descriptions mention has been made of increases which are really separate schemes for the near future. Probably, however, the next work of this nature to be carried out will be at one or more government projects in the North Island, for the Official Year Book has recently announced that "a large and comprehensive scheme is now under consideration for the supply of electrical energy in the North Island, with the object of making it generally available, as far as possible, to all the towns and districts throughout the Island. It is anticipated that advantage will be taken of the facilities offered to work the railways by electricity and to promote a system of light railways throughout the country districts now suffering from lack of communication."

Perhaps the most likely of these Northern schemes to be completed in the near future are those at the Huka Falls,

at Lake Waikaremoana, and on the Hutt River, in addition to those that have been already described. A brief reference to each may not be out of place.

It will be remembered that, of the various power opportunities in the course of the Waikato River, that at Hora Hora is the farthest from Lake Taupo, and nearly the least, while the Huka Falls are the nearest, and dissipate over twice the energy of the former. They are situated about 3 miles below the lake and are the simplest of all to develop. On the other hand, they occur at a rather more inconvenient distance from consuming centres than do the others.

Just above the falls, as shown upon the accompanying plan (Fig. 10), the whole river is confined within a gorge, less than 50 ft. in width, cut in a flat bed of solid sandstone

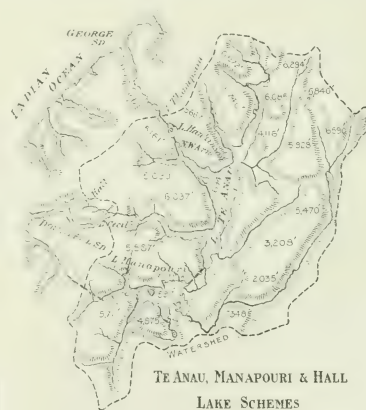


FIG. 9.

extending across the river valley. At the end of the defile the mass of water falls 50 ft., but the total drop, including the rapids above the gorge, amounts to 67 ft.

The plan (Fig. 10) shows a method of development recommended by Mr. Edmund Allo, though the same operations could be carried out almost equally well on the other bank. Provided a power house covering a considerable area is not required, the rock ledge shown at the termination of the proposed head-race, 6 ft. above the tail water, will form a most convenient site for the building. Otherwise, the opposite side of the gorge will probably be utilized. At the entrance to the head-race there is a natural bay, where the depth of water is 11 ft. For partial developments very little damming will be required.

Thus the work to be done consists mainly of 250 yards of fairly easy excavation, 60 ft. wide by 12 ft. deep; very short, nearly vertical pipe-lines; and the power house.

This was estimated by Mr. Allo to cost, in 1903, £20,500 for 3,000 kw., plus an extra £10,000 for each additional 1,500-kw. unit installed.

Lake Waikaremoana (Fig. 11) is interesting as furnishing the biggest scheme in the North Island. Slightly over 21 square miles in area, it is situated at an elevation of 2,015 ft. in the inland portion of Hawke's Bay Province. An area of 143 square miles of mountainous country is drained by the lake, possessing a rainfall of about 90 in. annually. Thus the Waikaretaheki River, which flows from the south-eastern arm, has a current amounting to 772 cubic feet per second.

Now this stream, at distances of  $1\frac{1}{2}$ , 2, and 4 miles from the lake, is observed to have fallen 760, 1,070, and 1,420 ft. respectively, and we should thus expect to obtain

fellow. There is a difference of level amounting to about 700 ft., and 4,800 h.p. should be obtainable at the present rate of outflow at comparatively little expense. Diversions could increase this to about 10,500 h.p., probably at only a moderate additional cost.

The Hutt River (Fig. 12) provides the most convenient scheme for the supply of Wellington city and the surrounding districts; the proposed power house at the Nurugaroa junction will only involve 24 miles of transmission to the city, while it is within much shorter distances of a number of smaller towns. Rising among the Rimutaka Mountains, the Hutt can produce a minimum flow of 300 cubic feet per minute just below its confluence with the Pakuratahi, though this will require a dam of about 150 ft. in height. However, at this point the river offers special facilities for

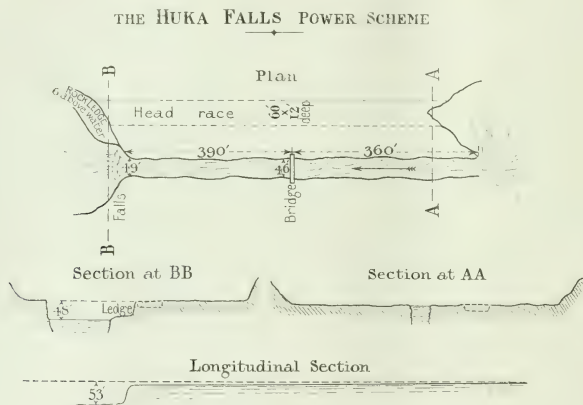


FIG. 10.

at these points no less than 75,000, 105,000, and 134,000 h.p. Unfortunately, however, the river issues from a number of underground outlets, which unite at a point 400 ft. below the lake surface. Unless, therefore, steps be taken to dam the arm in which the leaks occur, the capacities of the three schemes are reduced to 24,200, 44,900, and 67,700 h.p. respectively. It was estimated by Mr. Hay that this dam would involve an outlay of from £100,000 to £150,000, the narrowest part of the arm being 600 ft. wide. This is unlikely to be undertaken as part of the first development. Mr. Hay recommends in this case that a tunnel be bored in lieu of a pipe, roughly parallel with the stream. If the rock proves to be sandstone throughout, the cost will be about £20,000 per mile, and it will certainly produce a more permanent and generally satisfactory result.

A subsidiary scheme is possible without interfering with the main project, between Lake Waikareiti and its larger

the carrying out of such work, as it is confined by a narrow gorge of apparently solid rock, only 50 ft. wide. The effective head, in about four miles, separating the two tributaries, was given by Mr. Hay as 275 ft., and he estimated that at least 5,000 h.p. would be continuously obtainable; but the later statistics in Table 1 increase these to 365 ft. and 9,000 h.p. In the Water Power Act the cost was estimated at £300,000, for 10,000 h.p.

In the South Island, no great developments are projected for the immediate future, as the need is not now so great as in the North. On the other hand, the possibilities are very much greater. It will be sufficient here to devote a little attention to the lake-and-fjord schemes of the south-west, where huge quantities of energy can be obtained at a very low figure per horse-power developed, and per unit consumed. At the end of Table 1 is a series of 10 lake schemes, situated in this part of the country, representing an aggregate of 2,000,000 h.p. Of this total,

1,770,000, or more than seven-eighths, is derived from four of them (see Fig. 2), at Lakes Wakatipu (500,000 h.p.), Te Anau (750,000 h.p.), Manapouri (420,000 h.p.), and Hauroto (100,000 h.p.).

These great reservoirs are situated in the midst of mountain scenery of the utmost grandeur. Range follows range, running parallel for the most part in a north-and-south direction, hardly any of less than 5,000 ft. in height.

the most perfect harbours of the Dominion. It would be difficult, therefore, to imagine a more favourable region for hydro-electric development.

Of these, Te Anau may be taken as an example. It has an area of 138 square miles, and a drainage area of 1,354 square miles in the western portion of New Zealand, where the rainfall varies from 150 to over 200 in. per annum. The lake surface is at an altitude of 940 ft, but its bottom

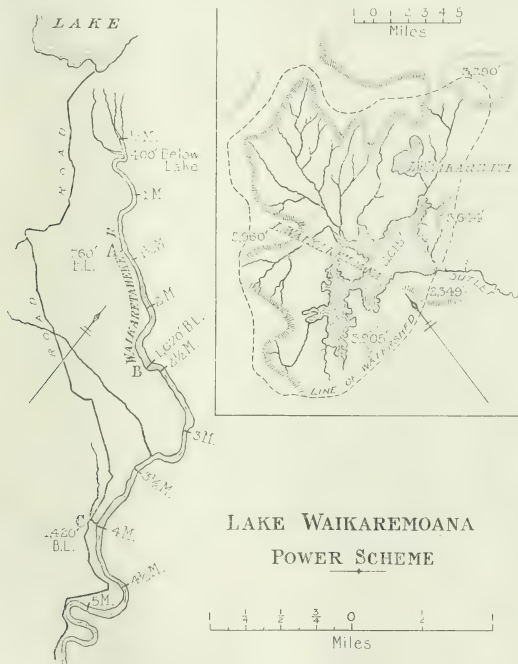


FIG. 11.

Over all the country are the marks of intense glacial action; in particular, the valleys are typically U-shaped. A large number of these old glacier beds now form remarkably deep basins, while the deposit of glacial detritus has given rise to many others. Several series of parallel lakes occur quite close together; and the water-levels are often widely different. For example, 66,000 h.p. can be obtained as the result of a head of 220 ft. between Hawea and Wanaka. Finally, a number of the largest approach to within a very few miles of the Sounds, which incidentally form some of

is far below sea-level. Its outflow is given as 12,630 cubic feet per second, but by conserving thoroughly this could be much increased. At one point, called the north-west arm, less than nine miles intervenes between the lake and George Sound, most of which is occupied by a succession of smaller bodies of water. By a channel of less than half a mile to Lake Hankinson, progress of three miles in the seaward direction would be accomplished. Accurate surveys have not yet been made, and it would be premature to go into further details; but there is little doubt

that the hydraulic work can be performed at a cost of under £5 per brake horse-power.

#### UTILIZATION OF POWER.

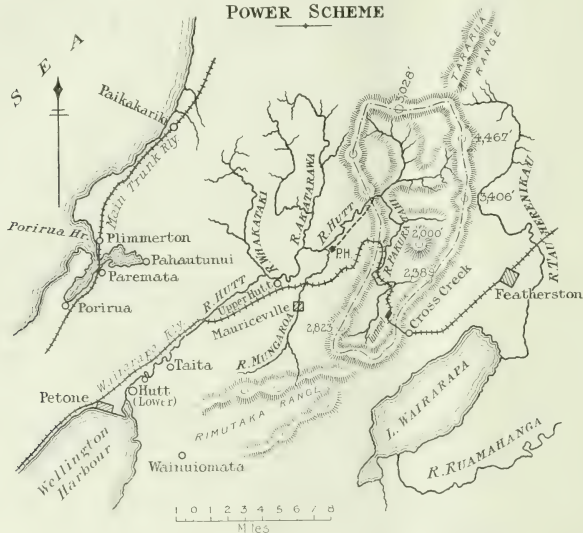
From the data that have already been supplied, it will have been realized that there is already a considerable demand for electric current for ordinary lighting and factory purposes all over the Dominion. This demand is growing rapidly at the present time in spite of the fact that publicity work on the part of supply authorities is rare. Older methods of drive are nevertheless being replaced, and new enterprises are beginning to spring up in places where current

Electricity would also be profitably used for irrigation and for drainage. An electric pumping scheme to water the fertile slopes of Whatatiri Mountain, near the Wairua scheme, is under consideration. There are also numerous shallow lakes, such as Ellesmere and Wairarapa, which would yield fertile tracts if drained.

Irrigation, for the cultivation of apple orchards at Cromwell Flat, Central Otago, is at present being carried out by direct water power. Two 660-b.h.p. Boving turbines are employed in this case, coupled to centrifugal, single-stage, double-entry pumps.

To employ, however, great power developments such

### HUTT POWER SCHEME



is cheap. A recent instance is the inauguration of a flour-milling concern in a country district of Canterbury, where the Lake Coleridge mains have just extended.

A brief mention has already been made of railway electrification. There are at present about 500 steam locomotives in New Zealand, many of which are of 75 and 95 tons, the former developing about 1,600 b.h.p. each. Heavy grades render railway traction a difficult problem in many parts, especially in the case of new lines. This consideration would favour electrification, as would also the large number of single-track tunnels, in which the smoke nuisance frequently attains serious proportions. With cheap power obtainable, it is quite likely that the present balance in favour of steam may be reversed before many years.

as those of the sparsely-peopled lake country, electro-chemical and electro-metallurgical industries must come into being. Fortunately, raw material for many of these abounds. New Zealand is endowed with a very wide variety of mineral products. On the other hand, these are often so scattered that hitherto a number of them have remained unworked. Others, such as iron ore and scheelite, have been exported to the Continent of Europe for treatment.

It remains to be seen to what extent the existence of cheap electricity will facilitate the treatment and encourage exploration for these. New Zealand imports at present all her own pig-iron, and the time is nearly ripe for local manufacture. The deposits of iron ore are remarkably

abundant and pure, the magnetite sand of Taranaki and Westland being especially adapted for electric smelting. These, and the huge limonite beds on the west coast of the Nelson Province, are situated in particularly accessible situations for sea transit, and flux materials are near at hand. Pure limestone deposits exist in great quantity in several places in both islands, and anthracite coal is worked at Paparoa, in Westland; it is probable, therefore, that calcium carbide could be produced.

There is a very real demand for nitrates in the Dominion itself and in Australia for fertilizing purposes; and there is no reason why alkali and chlorine products should not be manufactured for export. Some of these suggestions may seem to partake too much of the nature of novelties; but New Zealanders have shown their aptitude for pioneer work in the past, notably with the cyanide process for the

treatment of gold ores, and can do so again. Altogether, there seems little doubt that a ready field will present itself for the utilization of the power when available.

#### CONCLUSION.

It should then have been sufficiently established that hydro-electric power in New Zealand is plentiful, cheaply produced, and useful. Add to this the proximity of many of the largest power houses and prospective electrical factories to deep-water harbours, the existence of an unusually good and healthy climate, and other favourable local conditions, and also the wise and liberal Government of the British type in power in the Dominion; under such advantageous circumstances the field for the generation and utilization of electric energy cannot but be a particularly bright one.

## DISCUSSION ON

### "THE DESIGN OF HIGH-PRESSURE DISTRIBUTION SYSTEMS."

WESTERN LOCAL SECTION, 13 DECEMBER, 1915.

Mr. W. A. CHAMEN: A statement made near the beginning of the paper rather startled me. The author says that as time goes on we shall do more and more of our distribution at high pressure. I take him to mean, however, that we shall do far less of what he calls low-tension distribution from any one sub-station. We shall cut up our areas, and divide them over a much larger number of e.h.t. transformer sub-stations. It is wonderful to see the large number of sub-stations in the Newcastle Electric Supply Company's system, and also the number of generating stations. It would be of interest to us if we could know what would be the effect if some of the waste-heat stations suddenly collapsed, from accident or any cause, and ceased giving their supply. Is this extensive distribution system so arranged that any one of these auxiliary generating stations can be shut down and still allow the whole concern to go on without any interruption? With regard to overhead lines, some of our experiences in South Wales have been most interesting. In each case, I think, where we put up an overhead line working at 11,000 volts the birds have at first been a great trouble. They stand on the crossarms or pole tops and manage to reach the wires, causing a short-circuit and sometimes shutting down the supply, as well as killing themselves. This happens for a little time, but soon the birds begin to learn—at least the next generation of birds does—that it is dangerous and this trouble ceases.

Mr. J. W. BURR: Like the previous speaker I cannot quite understand the author's remarks on page 125 concerning distribution, which he states will eventually be at high pressure practically to the consumers' premises. I take it that his idea is to have many high-pressure sub-stations and to supply only in the immediate locality of these sub-stations with low pressure. We will obviously

require not only a great number of sub-stations but also a dense distribution area in their neighbourhood. I am afraid the majority of central station engineers have not to deal with an area in which this is possible. After reading the "General Principles" on page 126 I was almost led to think that I was living once again in my Deptford days. With regard to safety in operation, I am afraid we engineers have little or no option in the matter, as the Board of Trade now require us to comply with certain regulations which make the system not only safe for the public but also "as far as possible" safe for the operating staff. Regarding the suitability of supply, obviously this must suit the consumers' requirements. For instance, a short time ago I was requested to give a supply to a large works, and I suggested to them that they should take low-tension 3-phase alternating current. It was, however, pointed out to me that they had already a continuous-current installation at 235 volts. It was therefore necessary to install a rotary converter at their particular voltage or lose the business. With regard to the freedom of interruption, surely the author does not suggest that the supply from a power station is less reliable than the ordinary private supply. I heartily agree with him, however, that money spent on preventing or minimizing an interruption to the supply is money well spent, since reliability of supply must be one of our first considerations. I should like the author to explain what is meant by his remarks in connection with the desirability of keeping down capital expenditure at the expense of other items, and also to explain his method of a further way of reducing interest charges. The interest on the capital expenditure is a fixed charge and one that can only be reduced per unit by increasing the output. Probably, however, I have not quite grasped the point. Dealing with sub-stations, I notice the author says that cheaper labour

\* Paper by Mr. J. R. Boardman, pages 125 and 126.

Mr. Burr. can be employed if apparatus is designed to prevent automatically the most serious mistakes. I think, however, that in some cases the use of automatic apparatus is somewhat overdone; and I should rather rely to some extent upon the attendant and employ qualified men. After all, even automatic contrivances sometimes go wrong. In connection with overhead mains it is stated that these are more liable to break down than under groundmains. This may be so, but is it not a fact that faults are more easily localized and repaired on overhead than underground mains? I notice the author states that one of the disadvantages in connection with the use of overhead mains which must always be borne in mind is that they usually require a special wayleave. Am I to take it that he suggests it is more difficult to obtain a wayleave for an overhead line than for an underground main? I hardly think that is so. It would be of interest if he would give more particulars of the paralleling of overhead and underground mains. The difference between the current in the conductors seems to be very great. I should also like to know the length of the line, as self-induction is surely practically negligible in a moderate-distance transmission at a low frequency. I notice the author takes a frequency of 50; is this not high for power distribution? Obviously the inductance voltage is directly proportional to the frequency, and as this factor limits the power which can be transmitted over any line it surely should be reduced as much as possible. It would have been most interesting if he had dealt with this important point of frequency and its effect upon economical transmission. The author makes me feel quite nervous about my switchgear. I was certainly under the impression that switchgear was designed to-day that would operate successfully under almost any condition of working. Probably he has in mind the switchgear in connection with the huge power stations in the North of England. I am afraid that as far as I am concerned I must leave the matter with the switchgear designers and specify as nearly as possible my requirements. In connection with the most economical section of mains, it is, I think, a difficult matter exactly to calculate the most economical section, especially as the actual value of the losses is a varying quantity. I also am of the opinion that it does not normally pay to operate cables at the maximum current density allowed by heating limits. It would be interesting to hear how and where the author obtained all the information necessary for the construction of the numerous graphs. I heartily agree with a paragraph in his concluding remarks in which he says "theoretical calculations must, however, be used with caution." The results of the graph and the slide-rule should always be considered in conjunction with the results of practical experience and the whole sifted by the exercise of judgment, accuracy in which is the true test of an engineer.

Mr. Proctor. Mr. C. F. PROCTOR: I should be glad if the author could tell us the maximum output of the Newcastle stations, also the proportion between the power generated by the waste-heat stations and that of the main stations. With regard to the trouble with surge effects, I believe in the case of some overhead lines this is a serious matter, but that the system in Newcastle is now so large that they do not now provide protection against surges. Is this so? I believe it is usual in waste-heat stations to have a system

of charging customers so much for energy supplied through the mains into their station and to pay them for the energy which they give to the power-supply company, i.e. in and out, debtor and creditor. It would be interesting for us to know how the scale of charges is made. It is quite possible we cannot know the amount paid per kilowatt, but the percentage difference between what is charged for the respective supplies might perhaps be stated. In extra-high-tension switchboards has trouble been experienced from static charges of the parts? In a 17,000-volt switchboard I saw tested some years ago I noticed that sparks passed between any two metal parts (such as two screws) close together, although they were not supposed to be in electrical contact with any live parts. In the case of breakage of overhead cables, are automatic cut-outs provided for isolating from the earth; if not, does the cable remain alive to the earth until cut off at some point?

Mr. F. TREMAIN: It would be interesting to know whether open-air switchgear such as has been introduced in America has been adopted to any extent in this country. I was rather surprised to hear that the breakdowns of overhead lines were only twice as frequent as those on underground cables. It could perhaps be stated over what period this comparison has been taken. Also what is the definition of the term "breakdown"? I suppose that breakdowns of underground power cables are due sometimes to subsidences, which would not as a rule apply in main underground telegraph systems usually laid along roads. A 2 to 1 ratio does not seem, at first sight, to be sufficient difference between overhead and underground systems to justify the greater cost of subterranean cables.

Mr. C. T. ALLAN: It is interesting to note that the author's figures show the interconnected system to be the most economical. I quite agree that it is, but the problem is, how to introduce the protective apparatus upon an existing system having cables already laid? Where the roads are so full of mains, pipes, etc., of other concerns, it would probably be a most expensive problem to solve. When we desire to increase the voltages above the usual standard of 11,000 volts to say 20,000 volts and above, the increased cost of switchgear is a point that needs attention. With the protective systems mentioned by the author, it is to be noted that reliance for the operation of the clearing circuit breakers has to be placed upon current transformers, and we find that trouble with current transformers is occasionally experienced during lightning storms, so that they cannot be considered infallible. I should be much obliged if the author would explain a little more fully Figs. 10 and 13b. I can recommend the use of high steel poles, because wilful breakage of insulators is avoided; it is practically impossible to break an insulator on such a pole except by using a rifle. The author mentioned that the proportion of breakdowns on overhead lines was greater than with underground cables. Our experience has been the reverse; and certainly for quickness and ease of repair, overhead lines are to be preferred.

Mr. T. H. HAIGH: I am very much interested in the method of interconnecting feeders. Unfortunately it is difficult to arrange anything like that on mains which have been laid for a number of years. I should like, with Mr. Allan, to have certain of the curves further explained if possible.

Dixon.

Mr. L. W. DIXON: I have had little to do with large e.h.t. systems of late, but I am responsible for some 11,000-volt work and sub-stations. We (the Merthyr Electric Traction and Lighting Co.) take a supply at that pressure from the South Wales Power Company. I was on the staff of the latter Company some 12 years ago, having been one of their early mains engineers. At the commencement of the power company's operations there were no such luxuries as circuit breakers, and no private telephone system, such as they have now. On breakdowns of mains we had to rely on our watches to know when the main was dead. The question which Mr. Chamen asked with regard to the waste-heat stations shown in Fig. 8 also occurred to me, namely, what would be the effect if one of these waste-heat stations failed?

Beard.

Mr. J. R. BEARD (*in reply*): Both Mr. Chamen and Mr. Burr have interpreted quite correctly my views as to the future field of high-pressure distribution in the matter of domestic supply, and I would also refer them to my previous remarks in connection with Mr. Woodhouse's contribution to the discussion before the Institution.\* Progress in this direction is already being made in several large towns where extensive networks are being divided up into sections fed from different sub-stations. On the North-East Coast, about which I can speak with more direct knowledge, no extensions are now being made to continuous-current networks or to rotary sub-stations. In four or five instances, as the load increased, outlying portions of the network have been isolated and at the same time changed over to alternating current so that the additional load can be dealt with from a static sub-station. Mr. Chamen referred to the large number of sub-stations and generating stations shown in Fig. 8. I should perhaps explain that the sub-stations are not all controlled by the Newcastle-upon-Tyne Electric Supply Company. Quite a large number belong to the Cleveland and Durham Electric Power Company, and some also belong to certain groups of collieries which undertake their own high-pressure distribution; but although these groups are quite distinct from the financial and management points of view, they are operated as an engineering entity by means of suitable agreements between the respective parties. These agreements make provision for interchange of current where both parties are operating generating plant. The large number of generating stations is due almost entirely to the existence of sources of waste heat, and if these were not available the area would have probably drawn its supply from not more than three power stations.

Mr. Chamen and also Mr. Dixon asked what would be the effect of the failure of a waste-heat station. This is a matter which is automatically provided for, as in order to dispose of the surplus energy the station is necessarily connected by a high-pressure main to the general distribution system, and if the waste-heat station fails the flow of energy in this main reverses and the local supplies in the neighbourhood of the waste-heat stations are given from the main system. The loss in generating capacity can, in ordinary circumstances, be made up by drawing on the spare plant at the coal-fired stations. In other words this spare plant, which would be required in any case whether waste heat is utilized or not, is enabled

by the interconnected system to act as a spare, not only to the plant at the generating station where it is installed, but also to a large number of waste-heat generating plants at widely separated places. In the unusual event of a number of waste-heat stations failing together, due for example to a coal strike, the loss in generating capacity will usually be balanced by a drop in the load on the system unless the output of the waste-heat stations is very large relatively to the coal-fired stations. Where the waste heat is in the form of gas which is burnt under boilers, even this contingency can be guarded against by making arrangements for tar-firing in emergency.

The trouble experienced on overhead lines from birds in South Wales is identical with our experience in the North. Various means have been tried to overcome it, such as insulated sleeves over the cross-arms, but they have not proved entirely satisfactory, and the more recent lines are being put up with suspension insulators, which should quite prevent any trouble at the poles. A further trouble we have experienced is apparently due to a flock of large birds settling on a particular wire in a particular span, with the result that the sag of the wire in question is increased to such an extent that it, or a bird on it, comes into contact with the wire of another phase. The evidence of this is that in several cases the wires have been found burnt in the middle of a span and a dead crow on the ground underneath. I myself have seen a span about half covered with crows and a noticeable increase in the sag. Fortunately, as Mr. Chamen points out, these troubles are usually confined to the first year or two that a new line is in commission.

I think Mr. Burr has taken rather too seriously my opening remarks on "General Principles." Many of these were restatements of quite well-known principles, but it was necessary to refer to them in order to make my treatment of the subject complete. I cannot, however, agree with him that safety in operation is automatically obtained by compliance with the Board of Trade regulations. These are very useful and complete, but like all such legislation they merely enforce a minimum standard. It is hardly necessary for me to say that I consider a public supply, which is managed by specialists in the matter, to be much more reliable than any private supply. I do not think I anywhere suggested that capital expenditure should be kept down at the expense of other items; in fact on page 126 I gave a warning against this being done. My suggestion for reducing interest charges had no reference to the reduction in capital charges per unit which can be obtained by an increased load factor. My point was that, if the supply undertaking supplies the whole of the load in its area, and if that area is large, the consumers will belong to a great variety of industries. Consequently, if one or two particular industries are passing through a period of depression, they will not have so great an effect on the revenue of the supply undertaking as would be the case if they constituted the bulk of the consumers. This results in an equalization of the revenue, and it is a well-known fact that the steadier the return on capital the cheaper the capital can be obtained. This applies more particularly to privately-owned undertakings, as municipalities can obtain money for electrical purposes at low rates of interest, owing to the steadying effect of their other branches of activity and to the collective guarantee of the community.

Mr. Beard.

\* Page 231.

Mr. Beard.

Both Mr. Burr and Mr. Allen refer to the relative ease of carrying out repairs on cables and overhead lines, and I agree with them that in daylight hours overhead lines possess some advantage in this respect except with very long spans. The wayleave question is of more importance with overhead lines because they are usually erected on private property, owing to it being contrary to the regulations for a high-pressure overhead line to be erected along a public road. Cables, on the other hand, are usually laid in public roads where the supply authority has statutory power to lay them without any wayleave. My figures for the distribution of the current between a cable and an overhead line in parallel are calculated from the usual formula

$$\frac{I_1}{I} = \sqrt{\frac{R_2^2 + S_2^2}{(R_1 + R_2)^2 + (S_1 + S_2)^2}}$$

in which  $I$  is the total current before the circuit branches,  $I_1$  the current in one branch,  $R_1$  and  $S_1$  the resistance and reactance of that branch, and  $R_2$  and  $S_2$  the resistance and reactance of the other branch.  $I_2$ , the current in the other branch, is obtained by a similar formula. As both resistance and reactance are proportional to the length, the length cancels out of the above expression and hence does not affect the distribution of the current. The actual figures which I have taken in my calculation, expressed in ohms per mile per phase, are  $R_1 = R_2 = 0.287$ ;  $S_1 = 0.137$  (cable);  $S_2 = 0.57$  (overhead line). The effect would be less at a lower frequency, and I agree that for the distribution system (as I have defined this term in the paper) a low frequency has some slight advantage. The question of frequency is, however, of chief interest in connection with generating and transforming plant and consumers' apparatus. The slight influence it may have on the distribution system will carry no weight when the matter is being settled, and hence the consideration of frequency is not germane to the subject of the paper. Mr. Burr will probably get reasonably satisfactory results on his system by specifying the duty he requires from his switchgear and leaving the rest to the switchgear designers, provided that he adopts the advice of our President in his Inaugural Address\* and does not buy on the basis of the lowest tender. It is almost impossible to specify stringent tests for switchgear which will ensure that all tenders are on the same basis; and consequently, in this case even more than in most, the price may be a very poor guide to the most advantageous offer.

Mr. Proctor has asked for information on a number of points in connection with the North-East Coast system, but, as he surmises, I am not at liberty to give him definite figures. I can, however, give him some rough indications which may be of interest. Two years ago the output had already exceeded one million units per day, but as the load factor is high the maximum demand has not yet reached 100,000 kw. The units generated by the waste-heat stations are about one-quarter of the total. In the case of a waste-heat station the natural principle is that as most of the surplus units are usually sent into the system off the peak they will be worth something less than the coal cost; the price of units supplied from the main system will of course depend on the load factor and the demand. As Mr. Proctor states, surge effects do not cause much trouble on a large

system, and our experience has been that the less the amount of apparatus for protecting against surges the less is the trouble experienced. For the overhead lines we at present rely entirely on taking them into sub-stations through a short length of underground cable. After the lightning storms last summer, statistics were prepared which showed the benefit of this in a striking manner. Nearly all cases of trouble occurred on overhead lines brought direct into sub-stations; a few cases occurred where only short lengths of cable had been used, say 20 to 30 yards, while in those cases where longer lengths of cable had been used no trouble at all was experienced.

Trouble is not experienced from static effects on switchgear, as care is taken to earth all metal parts which are not alive. The automatic isolation of broken overhead lines is a difficult problem, as the earth resistance is often so high that only a small current passes under the fault conditions. This is usually insufficient to operate overload gear and is occasionally not sufficient to operate balanced-current protective devices. The split-conductor system is the most sensitive means of dealing with such faults and Mr. Trotter has pointed out its advantage for this purpose. In certain circumstances it is sensitive enough to operate before the broken wire touches the ground. The high resistance of such earths is not generally realized, and it may be of interest if I give some idea of the values which are obtained under practical conditions. In this country under very dry and unfavourable conditions the resistance between a broken wire and earth may be as much as 100 ohms, and several instances have occurred where values of 30 to 50 ohms have been obtained.

In reply to Mr. Tremain, I do not know any instances of the use of open-air switchgear in this country. In America its use has been encouraged by their very high transmission pressures and the undeveloped state of the country, but I do not think it is likely to be suitable to the conditions here. The comparison between the numbers of breakdowns on overhead and underground mains was based on a period of one year, but it is also confirmed by the experience of previous years in which the improvements in overhead-line construction had gradually reduced the proportion. It is, however, evident from Mr. Allen's remarks that the experience in one district is not necessarily the same as that in other parts of the country where the local conditions may differ. By a breakdown I mean a permanent fault which does not allow of the switches being closed again until repairs have been effected. Faults caused by birds often trip out a line with no other damage than that suffered by the bird; this would not be classed as a breakdown. Cable breakdowns from subsidence are usually at joints and can be almost entirely avoided by fitting "Vernier expansion joints." I imagine that on a multicore small-wire cable, such as a telegraph cable, the joints are relatively stronger and the whole cable more flexible.

Mr. Allen and Mr. Haigh mention the difficulty of introducing protective apparatus on cables which have been already laid. With the balanced-current system it can only be done by laying pilot cables, but it is often possible to draw these into spare ducts. Alternatively several pilot cables may be laid in a single trench as it is not necessary that the pilot should exactly follow the route of the cable it protects. A number of the older Newcastle feeders

\* Page 1.

Beard. have been dealt with this; but usually a more convenient method, when adapting an old radial system into an interconnected one, is to group the old feeders in pairs, where they follow the same route, and treat the double cable as a single split-conductor feeder. This method has been already used with success, and I know of several instances where it is now under consideration. In connection with the increased cost of high-voltage switchgear, I would refer Mr. Allen to my reply to Mr. Pearce's contribution to the discussion at Manchester.\* Single-turn current transformers with heavy-section primaries and sound insulation do not give much trouble, but, even if failure should occur, both the protective systems mentioned in the paper would most probably come into operation. Mr. Allen asks me to explain Figs. 10 and 13*b* more clearly. Fig. 10 will be clearer if it is borne in mind that the current is assumed to be constant throughout, whatever the power factor. This is a permissible assumption in the case of a new system, since it has been shown that there is a certain current density which is most economical, and this does not depend on the power factor. For a main already in existence which has to carry a given number of kilowatts, the slopes of the curves would be much steeper. The ordinates would then be "the ratio of the 'voltage-drop at unity power factor' to the 'voltage-drop at unity power factor' with constant kilowatts," and all the values in Fig. 10 would have to be increased by dividing them by the particular power factor. Fig. 13*b* can be best explained by reproducing a sample of one of the groups of curves from which Figs. 13*a* and 13*b* have been obtained. This is shown in Fig. B herewith, which refers to a loading of 1,000 kw. per sub-station and an average of two switches per mile of main. It will be seen

from this that the voltage which gives the most economical system is 10,400, while for an increase of 5 per cent in the cost of the system the voltage can be reduced to 7,500 or increased to 14,200. The first figure agrees with Fig. 13*a*,

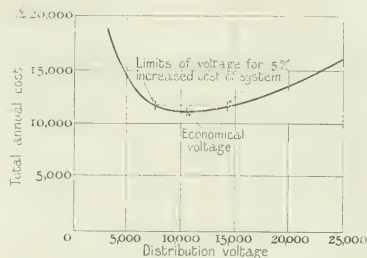


FIG. B.—Typical curve showing variation of the total annual cost of the distribution system with distribution voltage for a sub-station maximum demand of 1,000 kw. and an average of 2 switches per mile of main.

and the last two figures with Fig. 13*b*. Mr. Allen's proposal for avoiding malicious breakage of insulators by the use of high poles seems to me to be a rather expensive one. In Newcastle it has been found that the use of brown or green insulators makes them inconspicuous and is sufficient to prevent serious trouble of this description.

## DISCUSSION ON

## "SOME DIFFICULTIES OF DESIGN OF HIGH-SPEED GENERATORS."

YORKSHIRE LOCAL SECTION, 8 DECEMBER, 1915.

Mr. Woodhouse.

Mr. W. E. WOODHOUSE: The paper deals with a subject of great importance and one obviously full of difficulties; the steel-maker, the constructor, and the designer have in recent years been forced into a rate of progress too rapid for the state of their knowledge and as a result the user of turbo-alternators has in many cases become an unwilling assistant in costly experiments on a large scale. A free interchange of experience in problems of this kind is much to be desired, and the author's paper is very welcome. The primary problem is that of obtaining suitable materials to withstand the working stresses, and in considering this matter it must be remembered that every steel forging is first of all a casting, subject to all the curious weaknesses of cast metal. How far the final forging differs from the casting depends very largely on the amount of pressing, hammering, and rolling done on it; all these processes have an effect which is comparatively only skin deep, and therefore the properties of a large forging are more dependent on the ingot than on the later mechanical processes. An excellent example of the effect of the mechanical treatment of steel is the case of plough steel wire such as is used for colliery winding ropes, in which an ultimate tensile strength of 125 tons per square inch is obtained without any undue loss of elasticity. Large masses of metal cannot be worked in this way, and the plate construction by reducing the size of the forging must go far to ensure greater uniformity and strength. The design removes from the bulk of the metal in the rotating parts all bending and torsional stresses except those small ones due to driving the winding ends, which is all to the good, but the built-up rotor is, as compared with a solid one, loosely assembled, and the stresses acting on the coupling bolts due to torque, twisting, and other forces, aided by repeated heating and cooling, may conceivably result in a real loosening of the parts. Experience only can show whether this possibility will result in trouble. The shaft flanges and the end-rings are still difficult problems and limit the strength of the combination. It would be of interest if the author would say what alternative constructions are possible for rotors of this size and what is the limiting peripheral speed for the threaded plate design usual in smaller machines.

Unbalanced loads on the stator phases are well referred to in view of the increasing use of single-phase furnaces on 3-phase systems; extra losses due to unbalanced loads mean extra heating and the rotor windings may be dangerously overheated as a result. This is particularly the case at the winding ends where the cooling arrangements are deficient as compared with the parts embedded in the slots. The author's remarks as to external short-circuits are very much to the point; it seems, to say the least of it, unwise to accept as satisfactory for commercial use a machine which has not withstood a short-circuit test, and it is hoped that makers will regard this test as essential on all machines. First cost in large turbo-alternators is an important consideration

\* Paper by Professor A. B. Field (see pp. 65 and 171).

to the user, but the failure of such a machine on load may cause losses out of all proportion to the saving effected by adopting a design pinched in essential respects. One hopes that future developments will be on sounder lines.

Mr. W. E. BURNAND: The limitations of design for continuous-current machines, are, I believe, still due to the speed. With the alternator, of course, more progress has been made. On page 67 the fact that the 4-in. diameter bolts stretched as much as 1/10 in. with the initial tension gives a vivid idea of the stress on them. The extension seems considerable, but being well within the elastic limit trouble need not be anticipated. The expedient of using a crane to tighten these bolts requires a rather expensive tool, but it may be justified if it does not involve delaying other work by waiting for the crane. The author gives it as his view that the critical speed should be above the running speed, and provided that it is well above the speed of the generator I should say that it is sound practice. There is only one point against it, namely, the higher the critical speed the more violent are the effects when that speed is reached. That is rather in favour of the lower critical speed—the lower the better. On the built-up rotor the author's reasons seem correct for assuming that when the critical speed is reached above the running speed the critical speed drops if the vibration is such that the bolts stretch until the compression on the plates is relieved in places; but I should like to know whether actual experiments have been carried out to prove that assumption. The wording of the opening paragraph in regard to ventilation of the rotor does not, I think, give the intended meaning. It states that it is extraordinary how large a loss in the rotor can be dissipated without any ventilation, but of course as the rotor loss has to be dissipated mainly through the air surrounding the rotor, it shows the excellence of the ventilation round the latter, or the large loss that can be dissipated from the rotor surface without special air ducts owing to the extremely high speed. The addition of air ducts (Fig. 3) is not a very big increase on the rotor surface, and there does not seem such a great increase of the cooling surface as might be expected, but to a large degree their effectiveness is due to improving the ventilation round the surface of the rotor itself. The paper would have been more interesting if the author had given instances of some of the many promising devices that have failed to overcome the difficulties they were designed to overcome, since often much more can be learned from failures than from successes. I should like also to know whether he has had experience of turbo-alternators in which the armature rotates and the field magnets are the external part. I can see difficulties with the built-up arrangement owing to the large number of plates, but these difficulties do not appear to be insurmountable. Such machines would take the shocks of a short-circuit better, since it is the armature coils that chiefly tend to be deformed by these shocks, and the old

Mr. Woodhouse.

Mr. Burnand.

experiment of firing a candle through a board shows the increased ability to withstand shocks without deformation in the case of a high velocity. Also, salient poles are then possible, with a more efficient utilization of the field copper in one coil than is effected by the more usual arrangement of a rotating field. Improved ventilation is also obtained and a smaller iron loss owing to the open construction and the smaller length of the magnetic circuit subject to cyclic magnetic reversal. Combined, these advantages appear to me to justify much more development work than this type of machine appears to have received. Apart from this question of types, the means adopted to overcome the difficulties of design of these high-speed machines have done much more than develop the modern turbo-generator; they have led to more rigidly precise design all round, have helped materially to make special uniform high-quality material commercially available, and have set up a new and higher standard of workmanship, all having a progressively good influence extending outside the immediate circles concerned.

MR. W. M. SELVEY: I wish to express my high appreciation of the spirit existing in both the author and the American Westinghouse Company which thus enables us to get some idea of the efforts which have been made to solve the problem arising out of the demand for large units of power plant. While such a highly technical paper gives small opportunity for a general discussion, the author's remarks in regard to the cynical buyer give opportunity for some reflections. The cynical buyer is the natural outcome of the circumstances which educated him. An engineer who has a large reserve of old plant on his hands which is perfectly reliable but relatively inefficient, can afford to buy the latest plant and risk the undeveloped troubles that in general always arise in new types of plant. My experience has brought me into contact with many such troubles, and I have formed the opinion that the seriousness of troubles largely arises when the unadvised buyer takes on (generally at the seller's recommendation) the latest type of plant, having no spares for it and no intention of providing any such spares. Now, it is quite correct for Manchester to lead progress by buying 5,000-kw. 3,000-r.p.m. machines, but it would be incorrect practice for a concern whose whole load is to be carried by one such machine without adequate spares, especially at the same epoch of that evolution through which these machines will undoubtedly pass. Such a practice as the latter is uncommon in municipal concerns, but not so uncommon in industrial concerns, which often place orders purely on price. At the present state of power production the advantage of higher speeds is largely in the direction of producing larger turbo-generators without unwieldiness. Already these sets are so large that if built on one shaft their exhaust blade area is insufficient to take full advantage of the high vacua easily producible by the best modern riverside condensing plants. Their cost per kilowatt falls very slowly, hardly sufficient to affect the selling price of electrical energy. Their switchgear difficulties are largely increased, and added restraints must be employed. There is, however, a smaller staff and perhaps smaller land and building charges. This seems rather to support the cynical buyer's position, and yet I believe that on the whole we shall progress along the lines of bigger outputs at higher speeds. Should, however, their

employment become a fashion rather than an appreciation, Mr. Selvey, we must expect some set-backs. Having thus stated the need for caution one is now free to pay a very warm tribute to the engineering skill and technical ability shown in the work described. The electrical engineer is now beginning to put pressure on the steel-maker, and states that for some purposes our 30-ton steel is useless. He is now getting 40-, 60-, and even 80-ton steel and finds it too costly, in too few hands, and also as regards radial stresses in the interior in an evolutionary stage. This is quite understandable in the light of Professor Arnold's researches, which show definite segregation movements of carbon, phosphorus, sulphur, manganese, and nickel. An increase in carbon towards the centre would probably account for the suggestion on page 67 as to internal initial stresses in forgings. The necessary annealing temperature for the interior portion may be different from that for the exterior and may not be attained. I suggest that if segregation cannot be eliminated we should aim at making definite use of the tendency by endeavouring to direct it to act towards the centre, and then afterwards by removing the interior of the ingot. The remaining hollow cylinder could then be slit and opened out into a plate. One way of doing this would be to cast a short thick ingot around a chilled centre. After working this there will be none of the original structure left. At the same time I am not convinced that either a solid forging or a threaded plate design are impracticable, as we are tied to this scheme for the exhaust end of the turbine which will operate at a peripheral speed in advance of the rotor. It is curious that, after all, the design in question eventually came down to using really reliable 30-ton steel, showing that sound rather than extra-high-tensile material is required. I am not certain that such high ductility is necessary. An interesting account recently appeared in *Engineering*† on "Mayari" steel, a natural nickel-chrome steel which would appear to be a hopeful material for the future. I should like to ask Professor Field what is his criterion of merit for these new outputs. I have been accustomed to think in  $\text{k.w.} \times (\text{r.p.m.})^2$ ; Mr. Baumann's‡ paper on turbines suggests  $\text{k.w.} \times (\text{r.p.m.})^{3/2}$ . I append a table showing how matters are moving, taking our most sound present-day generator, a 5,000-kw. 1,500-r.p.m. machine, as unity.

# PROGRESS IN OUTPUT FACTORS.

Size of Machine kw	Speed r.p.m.	$C_1 \times \text{k.w.} \times (\text{r.p.m.})^2$	$C_2 \times \text{k.w.} \times (\text{r.p.m.})^{3/2}$
5,000	1,500	1	1
3,000	3,000	2.4	1.7
5,000	3,000	4	2.8
6,250	3,600	7.2	4.0
10,000	2,400	5.12	4.0
20,000	1,800	5.76	5.3
30,000	1,200	3.84	3.86
35,000	1,200	4.47	4.51

On the question of rotor ventilation I do not think the author really means that washed air is a disadvantage. It has always seemed a curious thing to me that in spite of

\* *Engineering*, vol. 100, p. 542, 1915

† *Ibid.*, vol. 100, p. 548, 1915

‡ *Journal I.E.E.*, vol. 48, p. 805, 1912

**Mr. Selvey.** such low voltages as are employed in rotors, electrical faults are far from uncommon. On the subject of stator ventilation the question of the necessity of a large central vent is very pertinent, and it would be most instructive to have a diagram showing the method of dealing with the magnetic fringe in the stator vent and for the avoidance of tooth breakage through vibration. Has the author had any experience of how these machines of a later type with magnetic characteristics as stated at the foot of column 2, page 129, run in parallel with smaller machines which do not have so small an air-gap or drooping characteristics? I have in mind especially the way a waltless kick would be shared between them. In speaking of the retardation shock to the rotor on short-circuit the author does not mention that the same shock is experienced by the stator stampings. I am not satisfied that this consideration always receives the attention it deserves at the hands of designers. It seems curious that in the shape of magnetic slot wedges, etc., we are nowadays deliberately adding reactance to generators. If this can be done as a protective measure without unduly increasing heating losses, it seems a more natural solution than adding an external reactance, unless this can be furnished naturally by a step-up transformer necessary for a transmission voltage. The solution of fitting what appears to me to be equivalent to a short-circuited winding of a static transformer to deal with magnetic pulses due to unbalanced load commands my admiration. I hope that the substantial stator and coil supports will not add an undue quota to the difficulties of cooling the stator end windings either by adding to the heat to be dissipated or by blocking the access of cooling air. The mechanical fixing of such end windings to resist short-circuit currents requires very careful design.

**Mr. Barclay.** **Mr. S. F. BARCLAY:** I should like to ask the author the following questions:—(1) What is the insulation used between the turns of the rotor winding? (2) With the wide rotor slot described by the author, is no trouble experienced in bending the rotor copper on edge? Is a power-driven machine used for bending the copper or is it done by a hand former? (3) No mention is made of the stator construction. Are the stator laminations dovetailed into the frame, or are they threaded on to dovetail-keys attached to the inner periphery of the frame? (4) With reference to Fig. 9, is no trouble experienced in moulding such a thick layer of micanite round the bend where the conductor leaves the core? (5) At the top of page 73 it is mentioned that the total loss on a short-circuit is very great in comparison with the product of the square of the current and the resistance of the stator winding. I fully concur with this statement, but I should be interested to learn if the author is speaking from observed results or if he has investigated the loss mathematically.

**Rotor-coil retaining rings.**—With regard to the steel rings for retaining the rotor end-windings, there is one point to which the author has not referred, namely, the opening of the rings due to the centrifugal force. For example, in the case of a typical 5,000-kw. 3,000-r.p.m. alternator when running at full speed the rotor ring increases 0.03 in. in diameter, and is therefore actually floating quite clear of its seatings. It is not practicable to prevent the floating by shrinking the rings on to their seatings. The floating may have several undesirable effects, but the principal one is change of balance. This undesirable feature is entirely

safeguarded against by making the ring and its outer supporting flange all in one piece. This construction is adopted by Messrs. Vickers as standard with all sizes of polyphase turbo-alternators. In the case of single-phase machines a similar construction is employed, but a band of high-tensile manganese bronze is introduced between the core and the steel ring. The extra cost of the solid steel end-ring compared with the built-up construction is justified by the mechanical soundness gained, and the construction also has other useful features. For example, the supporting flange can be given such stiffness that the ring does not need to be registered on the core; an effective gap between the core and the ring may thus be provided, very considerably reducing the magnetic leakage. Moreover, the opening between the ring and the core is most effective in improving the ventilation of the rotor end-windings. The short length of rotor coil between the core and the ring is given adequate support by extending the wedges beyond the core into the ring. The ring is made a sound press fit on its seating on the shaft, and is positively driven by keys of ample size. The complete ring is turned from a hollow nickel-chrome steel forging having an elastic limit of at least 40 tons per square inch, an ultimate strength of at least 50 tons per square inch, and a minimum elongation of 20 per cent. After being forged the rings are annealed, and after rough turning are re-annealed, oil-hardened, and tempered. The treatment ensures the rings being homogeneous throughout and free from appreciable initial stress. Circumferential and longitudinal tests are taken from each ring. Under any ordinary condition of out-of-balance, such as occurs on furnace work, etc., the solid steel end-rings are found to keep perfectly cool. The amount of out-of-balance for which the machines described by the author had to be designed is quite unusual, and no doubt it was desirable to introduce a little copper into the rings in the way described.

**Rotor wedges.**—The wedge described by the author is ingenious, but in my experience is unnecessary. If a good lead is given to the wedge and a metal liner is placed on the top of the coil, all the downward pressure desired can be obtained with an ordinary wedge. Moreover, the wedge described must require special tackle to apply the vertical pressure to the whole of its length, and that might be a grave disadvantage in carrying out a repair on site.

**Rotor construction.**—As the rotor revolves, the stress in the bolts increases as they move to the bottom, and decreases as they move to the top. Therefore, superimposed on the constant initial stress is an intermittent stress being applied and removed over  $2\frac{1}{2}$  million times a day. Since the bolts are a reamed fit in the core, the diameter of the screwed portion must be less than that of the body of the bolt. Therefore, the area of the bolt in the short length between the face of the nut and where the thread ends is appreciably less than that of the rest of the bolt. As the intermittent stress comes on, the short length of reduced area stretches more in proportion than the body of the bolt, causing local weakness. Also, the driving torque by tending to twist the rotor and increase the bolt length adds to the bolt stress, and a short-circuit must similarly add considerably to the stress. It is also to be remembered that the action of tightening the nuts must impose a considerable torsional stress on the bolts. It is therefore to be expected that a breakdown will occur in

**Mr. Barclay.**

the course of time in consequence of a fatigue fracture at the bottom of the thread just outside the nut. It would be interesting to learn how long the machines have been running, and if there have been any failures. The construction could have been improved by using high-tensile steel bushes, a reamed fit through the core, and with the bolts passing through them with an ample clearance, and turned down their whole length to a diameter slightly less than the diameter of the bottom of the thread.

**Solid rotor forging.**—The statement made by the author in the discussion before the Institution,<sup>2</sup> that steel manufacturers would not accept the test in a radial direction immediately below the surface, must be contradicted. The maximum stress in the rotor occurs at the root of the tooth, and from every forging made by Messrs. Vickers a radial test is made at that part, and no forging would be used unless the test showed that the properties of the steel were in every respect suitable for the duty. An example of the results obtained in the case of a rotor forging for a 5,000-

possible apology for the rotor built up of plates bolted together is that the construction saves money. In dealing with solid forged steel rotors, there are several essential points that must be observed:—(1) Large allowances must be made on the forging, so that all metal unavoidably damaged by the forging process is removed by machining. (2) By a thorough annealing after the forging has been made, and by re-annealing, oil-hardening, and tempering after the forging has been rough-turned, the forging must be rendered homogeneous and be freed from appreciable initial stress. (3) The rotor design must be such that at all parts the rate of change of stress is gradual and within the capacity of the steel. The average stress at any point may be quite low, but due to a too abrupt change of section the rate of change of stress may be too great, resulting in the crystals sliding over one another, and so causing a fatigue fracture to develop. Not only must the shaft between the journals and the core be carefully stepped, but also large radii must be provided at all

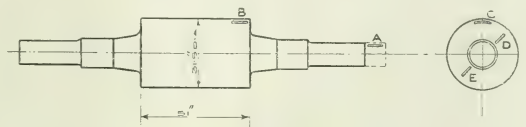


FIG. F.

kw. 2,400-r.p.m. turbo-alternator is given in the Table (see also Fig. F). It will be noticed that the tensile strength is

Test	Description	Elastic Limit Tens. per sq. in.	Breaking Stress per sq. in.	Elongation per cent on 2 in.
A†	Longitudinal	19.5	36.0	34.0
B	Longitudinal	20.5	36.0	32.0
C	Tangential	22.0	37	28.0
D	Radial	20	36.8	14.5
E	Radial	19.5	36.4	15.0

practically uniform throughout, and the elongation—even in the case of the radial tests—has a very satisfactory value. It is always possible to work to a factor of safety of at least 6 to 1, and when it is remembered that the tooth stress is a pure tension and constant in magnitude it shows how safe is the forged rotor construction. Provided that high-class forgings can be obtained, undoubtedly the solid forging is the ideal construction for all outputs at 3,600 and 3,000 r.p.m. For large outputs at 1,500 and 1,800 r.p.m. the soundest construction is to have a hollow forged cylinder shrunk on to a through shaft. With either construction a definite guarantee can be given for the strength of the steel in the direction required. The only

changes of section, and moreover all the radii should be formed truly and be given a dead-smooth finish. An additional point in favour of the forged steel rotor that will be appreciated by the purchaser, is that in the remote contingency of there being any flaw not detected by the tests and exposed by the machining operations, it is almost certain that the overspeed test at the makers' works would show its presence, whereas with a rotor of the kind described in the paper, any defects of design would most probably not be found out until the machine had been in service for some time.

**Critical speed.**—I can quite appreciate the statement made at the top of page 69, that the type of rotor described has no true critical speed, but the explanation given by the author is not clear. The area of the plates in compression is very considerable compared with the area of the bolts, and therefore the addition of even a few hundred pounds to the bolt stress would cause the bolts to elongate sufficiently for the plates to lose their compression and become loose. This opening and closing of the plates would effectively damp the natural transverse vibrations, and therefore the rotor would have no critical speed. This condition holds good if the fit of the spigots is free, but if they were made a good press fit, one inside the other, very probably there would be a definite critical speed having a value liable to change and difficult to forecast.

Mr. A. M. LAWRY: I should like to ask the author how Mr. Lawry. these high-speed sets operate in parallel, and whether it is possible, when two or more are in parallel, for a line frequency to exist which affects the speed of induction

\* Page 77.

† See Fig. F.

Mr. Lowry motors, but is higher or lower than the frequency shown on an indicator of the vibrating-reed type connected to the circuit.

Mr. H. H. WRIGHT : On page 68 the author rightly emphasizes the necessity of designing the generator for a running speed below the critical speed. If this condition is to be satisfied the distance between bearings must be kept as short as possible, owing to the fact that the critical speed is inversely proportional to the square of this distance. As the author points out, this may necessitate the omission of the blowers from the rotor, that is to say there is a point in the design of high-speed generators where considerations of size and speed preclude the possibility of using blowers. Other and external arrangements must then be made for ventilation. It would be interesting to know what the author considers these limits of speed and output to be. In cases where the critical speed is below the running speed, or where it is not possible to calculate the critical speed with absolute accuracy, good practice is to have the running speed at least 30 per cent above or below any critical speed. The Delaval turbine has been mentioned ; I think I am right in saying that is an exceptional case, and that steadier running has been obtained in that instance by designing the running speed to be 7 times greater than the critical speed, because a machine of this class has only one critical speed. On page 71 the author goes very carefully into the conditions arising for unbalanced load conditions, and the precautions to be taken to protect the magnetic steel end-ring from stray flux. The reasons are not clearly set out for discarding nickel steel for large machines as against chrome-nickel steel. The advantages of using the former material are very great magnetically. Nickel steel has a permeability of less than one-third of the latter. The method of protecting the steel ring also is interesting, but at the same time rather a costly construction. Doubtless other methods have been tried before the one described was arrived at, but I should like to ask whether the same results could not have been attained by electro-depositing a sheath of copper over the ring. On page 72 there is no very clear explanation of how the hard-drawn longitudinal copper dampers are electrically connected to the circumferential copper and bronze end-rings. In regard to the question of external short-circuits, much has been said about the advisability or otherwise of using external reactance coils with large turbo-generators, but I think the best engineering practice is against them, since they introduce a costly complication which is liable to break down and absorbs a considerable power, besides reducing the power factor and regulation of the system. It is now recognized that the advantages of being able to "dead" short-circuit a generator outweigh the disadvantages of a poor regulation. A generator that can be short-circuited when running fully excited or that can be inadvertently switched, standing idle, on the busbars, is one that any station engineer can put his confidence in, on emergency. The author mentions 14 times the maximum of the full-load current as the maximum possible short-circuit current in these particular machines under the worst conditions. That seems a very high figure, and one which it appears to me may cause damage to the generator. Will the author also give us the percentage reactance of these machines.

Mr. T. ROLES : I should like to ask the author to state what he considers to be the maximum safe rating of a 3,000-r.p.m. turbo-generator at the present time, as in the paper he has dealt more particularly with machines up to 1,500 r.p.m. A large number of 50-period machines are being built for 3,000 r.p.m., and the manufacturers seem to limit the size to about 5,000 kw. Can the author also give us some idea of the limits of capacity of solid-rotor machines for speeds of 1,500 and 3,000 r.p.m.? Such information would, I think, be very useful to the engineers who are responsible for installing and running generating plant. I am very pleased the author has mentioned the matter of supplying single-phase loads from 3-phase machines. Within the last month I have arranged to supply a single-phase load of 2,000 k.v.a., and am wondering how this load will affect our 5,000-k.v.a. turbo-generators, which were designed to deal with loads balanced to within 10 per cent. It appears to me that central-station engineers must now seriously consider the question of single-phase loads, as such loads are likely to increase in number, and it appears advisable when drawing up future specifications to stipulate that alternating-current generators shall be capable of dealing with large out-of-balance currents on any one of the phases without undue heating or considerable variation in pressure on any phase. I was very interested to hear the author's opinion that he does not consider it unreasonable for a purchaser or user to insist on seeing his machine short-circuited on the test floor or after erection. It has been my practice to put a clause in turbo-generator specifications calling for such a test, as it certainly appears to me to be desirable for all machines, before being taken over, to be short-circuited, preferably at the makers' works, but a number of the chief makers seem to consider a test of this description rather unreasonable, and a similar opinion has also been expressed by several station engineers when I have discussed this question with them. In connection with a contract I had to deal with a year or two ago a few manufacturers agreed to the short-circuit clause inserted in my specification ; the majority, however, declined to accept such a test unless a considerable amount of reactance was included in the external circuit. External reactances, however, are potential sources of trouble, and in certain forms are almost as liable to cause short-circuits as to minimize their effects. Such being the case, I consider that, if practicable, machines should be so built that they can safely be short-circuited without external reactance, and I am glad the author does not think it unreasonable to specify that machines should be built to comply with this condition. In conclusion, I wish the author would give us rather more details in regard to the method of attaching the coil-retaining rings to the rotor.

Professor A. B. FIELD (*in reply*) : Mr. Woodhouse has drawn attention to the way in which the physical properties obtained in steel depend upon the form in which the material is used, giving the very pertinent illustration of plough steel wire. This, indeed, gives us an ideal to aim at, or rather to ask the metallurgist to aim at, and when such properties are obtainable in steel of other forms and large sizes we shall be in a fortunate position for the design of much larger machines. The chrome-nickel steel that is used in the end-rings is a sample of what one

Professor Field.

can at present get in fairly large pieces by paying a high price. In continuous-current machines for high speed, steel banding wire is not infrequently used, with a strength even somewhat higher than that given by Mr. Woodhouse, and the idea of using a wire-wound end-ring for these rotors, to replace the chrome-nickel steel forging, was considered by us several years ago. Using such material, the total section of steel would be largely reduced, an advantage magnetically; the wire would have to be wound upon a thin steel drum, so that the ring would be entirely self-contained. However, there are many difficulties connected with such a construction which render it rather unpromising. The question was raised as to possible designs alternative to those described, and as to the limit of the threaded-plate type. Now that again is rather a matter of material. Comparatively big radial-slot machines were built a number of years ago by Behrend, using forged (not rolled) nickel steel plates threaded on a shaft; and even for the machines discussed in the paper, it would be possible to use a similar construction with chrome-nickel steel forgings for the discs. Perhaps, however, the advantage of putting a shaft through the structure is rather an imaginary one than otherwise, when we realize that even a 10-in. or 15-in. shaft is negligible so far as its stiffening effect is concerned. We have grown accustomed to shaft constructions, and are a little loath, both in shop practice and from the designing point of view, to depart radically from these; but a careful analysis of the conditions will indicate at various stages whether a through shaft continues to have any real advantage. There is, further, the possibility of using a single forging as an alternative construction; which again resolves itself into the question of reliability of material, and upon which much discussion has already been recorded.

In reply to Mr. Burnand, the suggested change of stiffness of the rotor, and consequently of the critical speed, should a vibration develop of amount sufficiently great to release completely the compression in some parts of the rotor, is not a result of tests, but purely theoretical. Mr. Burnand correctly interprets my meaning with regard to rotor cooling. There is in any case, of course, thorough ventilation of the machine itself; but one gets into the habit of distinguishing as a ventilated rotor one in which there are passages and openings cut for ventilation, as compared with a rotor in which the entire cooling surface is external: for instance, a plain cylindrical drum. I have had no experience with large alternators of the rotating-armature type, and fear that for such sizes as are here discussed the construction is far from practicable. It would certainly seem essential to use a through shaft when dealing with thin laminations, and the mechanical properties of thin sheet steel are not good, even in comparison with ordinary qualities of carbon steel, let alone high-tensile steel. The difficulties of high-voltage windings upon the rotating part would be very considerable.

Mr. Selvey puts very clearly the case for and against large units and new departures in construction, and I am in agreement with him here. He refers to Mayari steel, made from a natural chrome-nickel ore; this material has been used by us to a considerable extent, particularly in cases where the very best chrome-nickel steel properties were not required, and where carbon steel was hardly suitable. The material has good properties, and is

obtainable at a cost but slightly increased compared with carbon steel. Mr. Selvey correctly interprets my views with regard to cleansing the incoming ventilating air. My wording was not entirely clear on the point, and refers really to objections raised by purchasers to the complications involved in air-cleansing apparatus, and not in any way to the views of the manufacturers or designers.

Referring to the parallel operation of recent machines of poor regulation with some of the earlier types of machines, there appears to have been little difficulty in the actual practical operation in this respect; such parallel operation is in force in stations both with automatic voltage-regulators and without, but doubtless there must be a lack of correct distribution between the machines of the wattless kicks referred to by Mr. Selvey. The question of torsional shock to the stator structure as a whole in the case of short-circuits does not very often receive consideration; in the machines described a common construction of the stator core was used, with from 20 to 30 dovetail projections of the core into the stator frame, so that there is no possibility of difficulty arising on this score.

Replying to Mr. Barclay's remarks, I would say that the insulation used between turns of the rotor winding consists of an asbestos fabric. This material, when properly applied, will stand mechanical pressures several times as great as those occurring in the machine, as has been demonstrated by independent tests under hydraulic presses. The rotor copper coils are formed by a power-driven bending machine, with suitable precautions to ensure a uniform thickness of the copper at the bend in the finished coil. There is no serious difficulty in this edge-bending with such strips as are used, the conditions being not so severe as occur in common practice with some lower-speed alternators. As referred to already in answer to Mr. Selvey, the stator punchings are dovetailed into the cast-iron frame in a number of places. In some of these machines the core was insulated from the cast-iron frame by formed hard micarta shims at these dovetails, and the insulation was maintained towards the ends of the core by the insertion of a few insulating sheets at intervals. From a comparison of the test results, I am inclined to think that the core loss was not much reduced by this precaution. As regards the insulation upon the stator coil, the mica wrappers mentioned in the paper refer only to the straight part of the coil, so that the difficulty suggested by Mr. Barclay at the bend does not arise. As to short-circuit losses, the statement made in the paper with regard to the ratio of total loss on short-circuit to the calculated value of  $I^2R$ , is based upon the results of a large number of tests of alternators of all types and several makes. Mr. Barclay refers to the increase in diameter of the rotor retaining-ring when running at full speed, pointing out that there is a tendency for the ring to float clear of its seatings. I entirely agree that it is impracticable to prevent this floating by a shrinkage allowance on first applying the rings. I have found no difficulty of the nature of a change of balance due to this effect; and in fact in some of these rotors the lack of circumferential symmetry causes the ring still to bear upon its supports at some points in the circle. The method described by Mr. Barclay as being the standard practice of Messrs. Vickers, whereby the retaining ring

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FIGURE 1  
Field.

is made in one piece with its supporting flange at the outside end, is one that was used by Behrend 11 years ago. It has several advantages; one disadvantage is that the inward projecting flange prevents the proper distribution of stress in the material, since the ring is no longer free to expand as it should, and the stress at the bore of the flange is apt to be high. It is interesting to hear that, using this construction, an actual gap may be left between the ring and the body of the rotor, so that the ring is only centred in a positive way at its outer end. This construction was discussed by us some years ago, but it appeared inadvisable to allow this indefiniteness with regard to the ring centring. In some machines we extended the rotor wedges beyond the body of the core and turned them down to form a seat for the ring, thus giving the same magnetic effect as Mr. Barclay indicates, but with better mechanical conditions. But this again is somewhat objectionable, on account of the difficulty arising should it become necessary to remove and replace a rotor wedge. Regarding Mr. Barclay's remarks upon the 3-part rotor-wedge construction, I would refer to my reply to Mr. Hurst in the Birmingham discussion.<sup>26</sup>

Mr. Barclay draws attention to an important point with regard to the plate construction when he refers to the variation in stress in the long bolts as the rotor revolves. This is a point that received careful attention, and by a consideration of the relative areas of material in compression in the neighbourhood of the bolt and in tension, it was easy to determine major limits for the amount of the variation in stress in the bolt which is superimposed upon the assumed initial tension as the rotor revolves; it may be stated that this variation in stress is certainly less than  $\pm 700$  lb. per sq. in. We may go further and state that even should the rotor, through lack of balance, vibrate considerably, and vibrate to such an extent as actually to relieve the compressive stress on one side of the structure, we should still have our range of stress in the bolt less than  $\pm 6,000$  lb. per sq. in. Now, from the results of a large number of researches, starting from those of Fairbairn, Wohler, and others, we can definitely predict that a given range of stress superimposed upon another given initial stress will be as safe as a third determinate steady stress. Thus the failure by fatigue of these bolts should be capable of being accurately guarded against in advance. Again, researches on fatigue fractures point to failure occurring after a few million cycles, or at most a few hundred million, if at all. Hence the very frequency of stress variation, which Mr. Barclay cites in his argument, gives a safety indication of a most practical nature, entirely apart from theory or calculation, after the rotor has been running a few days, or months. Answering Mr. Barclay's question, I would say that there has been no failure of any bolt since this type of rotor was first put into operation some  $2\frac{1}{2}$  years ago. The driving torque is transmitted from thick plate to plate by the bolts acting as keys, rather than by the tension of the bolts due to a winding-up of the rotor structure as indicated by Mr. Barclay, and as would occur with a structure of thin laminae. Mr. Barclay enumerates some precautions that should be taken in this class of work as to heat-treatment, design for gradual changes of stress, fillets, etc., with all of which I fully agree, although it is often very difficult to obtain a proper

appreciation in the shop of the importance of smoothly finished fillets and complete absence of tool nicks in such places as referred to.

Mr. Barclay contradicts a statement which he attributes to me, to the effect that steel manufacturers will not accept a test in a radial direction on solid forgings. Such a statement was not made; but it is true that it did not prove possible in the States to obtain forgings of the size discussed in the paper upon the basis of our specifications. These involved a test upon a radial bar taken some little distance below the surface of the large diameter part of the rotor, and acceptance or rejection of the forgings was to depend upon the results of these and the other tests. It was the inclusion of the radial tests for acceptance and rejection which the steel-makers refused to accept when it came actually to placing orders, although tacitly agreed to in preliminary negotiations. I have had no experience in the matter in England, but from many remarks made during these discussions, and particularly from remarks made to me personally, it appears that the same difficulty has by no means been unknown by engineers in this country. Mr. Barclay gives some interesting figures for test-bar results on a  $3\frac{1}{2}$ -in. diameter rotor: it is unfortunate that both he and Mr. Juhlin<sup>25</sup> should have chosen for their illustrations rotor diameters for which, I think, we all agree that a solid forging should be used. I would similarly advocate a solid forging for all cases of 3,000-r.p.m. or 3,600-r.p.m. machines (of the type considered) which have hitherto arisen. As regards the advantage of the plate construction from the point of view of cost, this is not the feature upon which the construction can be greatly advocated, as the cost of the complete plate-built rotor, allowing for the machining operations, is not, I know, far different from that of a rotor built from a solid forging. I cannot state whether it is actually higher or lower. Referring to Mr. Barclay's last remark upon the critical speed, while the compressive area in the rotor is great compared with the bolt section, the change in bolt stress required for the plates to lose their compression is not as small as would be inferred from his words (see my figures given above in connection with fatigue fracture of bolts). The estimation of critical speed was made upon the assumption that the compressive stress was maintained, and the absence of any critical speed developing up to the over-speed test would indicate that this condition was met; for the critical speed would undoubtedly have been below the running speed for conditions involving a loss of compressive stress.

Replying to Mr. Lawry, no serious difficulty has been brought to my attention in connection with the parallel operation of these high-speed sets, although some of them have been installed in stations of a decidedly mongrel constitution. The effects he describes with regard to induction-motor speeds I have not heard of before, and they deserve further description, unless he refers merely to a small change in the percentage slip of the motor.

Mr. Wright refers to the question of external versus self-contained blowers, and asks for the limiting sizes dividing the two arrangements. As indicated in the discussion elsewhere, the question of incorporating the blowers in the machine is closely connected with the type of station in which the plant will be installed; and in

the case of entirely new stations with an ultimate large capacity it is likely that separate blowers may prove desirable, even for ratings of 10,000 k.v.a. or so; while from a constructional point of view it is not particularly undesirable to incorporate the blowers with the rotors for machines up to, say, 15,000 k.v.a. at 1,500 r.p.m. (50 cycles); self-contained blowers could be used, if greatly desired, upon the larger sizes also.

Reverting to the matter of the rotor end-rings, the difficulty of using non-magnetic nickel steel in these special cases is referred to in my reply to Mr. Dutton in the Manchester discussion.\* The method described of protecting the end-rings against the effects of the stator-coil field was the first one tried, although several methods had been considered on paper, including the one suggested by Mr. Wright. One difficulty in connection with any continuous copper sheath is that unless we can depend upon an actual adhesion in a radial direction between the sheath and the steel, we necessarily obtain a stress in the copper which is a definite and determinate fraction of that in the chrome-nickel steel, depending merely upon the increase in diameter under stress; that is to say, the ratio of the stresses in the two materials is in proportion to the values of Young's modulus of elasticity for the copper and steel. We should therefore certainly anticipate that after a short time the copper sheath would be loose upon the steel ring. The construction described is merely an artificial way of holding such a sheath radially down to the ring. The electrical connection between the longitudinal and the transverse copper is obtained by caulking. Mr. Wright considered the figure of 14, for the ratio of the maximum momentary short-circuit current to the corresponding rated figure, to be high; but perhaps he has compared this with figures obtained on a somewhat different basis. In short-circuiting the machine a number of times consecutively, the measured maximum would be on the average much lower; the figure mentioned was deduced from the oscillograms

\* Page 186.

and refers to the theoretically worst conditions. In a machine of the type described, but without any special provision for reducing the momentary current, such as the setting back of the stator windings from the air-gap by the use of the magnetic wedge, the maximum short-circuit current would be in the neighbourhood of twice this figure.

Mr. Roles is interested in the maximum size of 3,000-r.p.m. machines. For this speed it would appear practicable with our present resources to construct a machine up to seven or eight thousand k.v.a. maximum rating, provided that we are allowed reasonable specifications. Solid forgings would be suitable for such rotors. As to the limit of capacity for solid-rotor machines of 1,500 r.p.m., Mr. Roles has addressed his question to the wrong quarter. Indications have been given in the paper of the rotor dimensions required for these ratings, and the question is really that of the degree of reliability obtainable from solid forgings of these sizes. There have been many strong opinions expressed in these discussions on both sides of this question, and the matter is one to be decided mutually between the steel-maker, the constructor, and the buyer, as there is nothing *impossible* about constructing out of solid material the biggest machines that have heretofore been discussed.

The attachment of rotor end-rings is effected as follows: a narrow step turned on the end of the rotor both constrains the tip of the ring in an endwise direction and centres it. At the other (outer) end of the ring the bore is slightly increased for a length equal to the thickness of the end supporting plate, thus again centering the ring and giving endwise constraint. The end plate is located by means of a narrow threaded collar on the shaft, or a similar device, and is keyed to the shaft. It facilitates the assembly of parts to key-drive the ring at its inner tip; but where the use of a bronze tip section, or some other feature, renders this inadvisable the key-drive may be from the end supporting plate. The ring bore is slightly tapered to facilitate assembly.

Professor Field.

## PROCEEDINGS OF THE INSTITUTION.

## 583RD ORDINARY MEETING, 16 DECEMBER, 1915.

Mr. C. P. SPARKS, President, took the chair at 8 p.m.

The minutes of the Ordinary Meeting held on 25 November, 1915, were taken as read, and were confirmed.

The list of candidates for election and transfer approved

by the Council for ballot was taken as read, and it was ordered to be suspended in the Hall.

A paper by Mr. J. R. Beard, M.Sc., Associate Member, entitled "The Design of High-pressure Distribution Systems" (see page 125), was read and discussed, and the meeting adjourned at 9.46 p.m.

## 584TH ORDINARY MEETING, 18 JANUARY, 1916.

Mr. C. P. SPARKS, President, took the chair at 8 p.m.

The minutes of the Ordinary Meeting held on 16 December, 1915, were taken as read, and were confirmed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and it was ordered to be suspended in the Hall.

Messrs. C. C. Hawkins and G. D. Adam were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

## ELECTIONS.

## Member.

Jones, Stinton James.

## Associate Members.

Covell, William Gibson.	Shankster, George Charles.
Gilmore, John James A.	Stuart, Charles Edward.
Rice, Reginald Kenneth,	
Capt., R.N.	

## Associate.

Shrimpton, William Bruford.

## Graduates.

Boak, Charles Frederick.	MacIndoe, George.
Brook, Salomon.	Naylor, Thomas Liddle.
McEntee, John Francis.	Owen, William Emlyn.

## Students.

Braathen, Emil.	Pollard, Herbert.
Feest, Maurice Lionel.	Ross, George MacLeod.
Gleaves, Ernest Arthur.	Thomas, Frederick.
Godwin, William Henry.	Young, Sidney.

## TRANSFERS.

## Associate Member to Member.

Dowsett, Harry Melville.	Thomas, John Golfrey
Perrow, William Henry.	Parry.
Wilson, Joseph Geary.	

## Graduate to Associate Member.

Hurst, George Norman.	Lewis, William Reginald.
Mitra, Kshitish Chandra.	

## Student to Associate Member.

Calman, Cecil George.	Lovell, William Henry.
Cottle, Peter James R.,	Morris, Norman Herbert.
B.Eng.	Morrison, Alexander
Date, William Henry, B.Sc.	Michael.
Dixon, Thomas Archibald F.	Parry, William.
Elkins, Cyril Arthur I.	Robertson, Alexander
Fletcher, John Reid.	Thornton.
Linsley, Douglas Harold	Wood, George Herbert.

## Student to Graduate.

Blythe, William Herbert.	Parikh, Jekisondas
Haddock, Vivian Otto	Mohanlal.
Honey, Harold.	Rayner, David Dyson.
King, Edward Thomas.	Sparrow, Herbert Robert.

The following donations were announced as having been received, and the thanks of the meeting were accorded to the donors:—

*Benevolent Fund:* H. Alabaster, I. Braby, J. Burns, W. W. Cook, J. P. De Lima, W. Duddell, F.R.S., L. H. Euler, F. Gill, B. B. Granger, D. Henriques, H. Hirst, H. W. Kolle, W. E. Lane, Sir H. C. Mance, C.I.E., LL.D., E. Manville, C. H. Merz, W. M. Morrison, H. F. Proctor, G. S. Ram, W. R. Rawlings, A. Russell, D.Sc., S. G. C. Russell, C. O. Varley, T. C. Walrond, H. D. Wilkinson, and C. H. Wordingham.

*Building Fund:* H. Hirst, Admiral Sir H. B. Jackson, K.C.B., K.C.V.O., F.R.S., and H. W. Young.

*Library:* W. J. A. Butterfield, Messrs. Constable & Co., Ltd., H. W. Dowsett, The Engineering Standards Committee, V. A. Fynn, H.M. Inspector of Factories, J. E. Kingsbury, T. M. Lowry, F.R.S., Messrs. Macmillan & Co. Ltd., The New Zealand Society of Civil Engineers, Captain E. J. Stevens, and Le Syndicat Professionnel des Industries Electriques.

*Museum:* G. B. Bowell (loan), H. S. Ellis, and E. Pullum (loan).

A paper by Professor Miles Walker, Member, entitled "The Predetermination of the Performance of Dynamo-Electric Machinery" (see page 245), was read and discussed and the meeting adjourned at 9.50 p.m.

585TH ORDINARY MEETING, 20 JANUARY, 1916.

Mr. C. P. SPARKS, President, took the chair at 8 p.m.

The minutes of the Ordinary Meeting held on 13 January, 1916, were taken as read, and were confirmed.

Messrs. J. D. Dallas and F. Hope-Jones were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows :—

ELECTIONS.

*Members.*

Juhlin, Gustaf Adolf. Kuyser, Jan Arthur.

*Associates.*

Pirelli, Alberto. Pirelli, Piero.

*Graduates.*

Chakravarti, Sukumar. Schneidau, Tom Charles.  
Hopkins, Allan Valentine. Tombat, Sakharama Rao.  
Nair, Kilakethil Velayndhen. Ward, Henry John.  
Wood, Leonard Ernest.

*Students.*

Burkitt, Stanley Thomas. Hollin, Archibald Stewart.  
Cook, Francis Ainsley. Housden, Frank R.  
de Arana y Bengoechea, F. Jacob, Gabriel Gordon.  
de Latheiros, Affonso Lopes. Japp, Reginald Francis.  
Duckworth, Herbert. Lazarus, Samuel.  
Dunnill, Fred. Malta, Euclid Filho.  
Evernden, Harold Ivan F. Martins, Almir Machado.  
Fletcher, Godfrey Herbert. Partridge, Douglas Grenville B.  
Galveas, J. Petch, Herbert Stanley.  
Goodwin, John James. Ramaswami, Erode K.  
Greenhill, Antony. Read, Robert Charles.  
Harben, Norman Roy. Richards, Leslie Cameron.  
Harral, Richard Harold. Seaward, William.  
Harrison, Alan. Senior, Ronald Cedric.  
Hasselt, Marc van.

*Students—continued.*

Serner, Arthur. Wall, Harold Henry.  
Sich, Walter, Ebray Egbert. Webb, Clifford Ernest.  
Smallcombe, Louis Stanley. Whitney, John Stuart.  
Smith, Hugh Leslie. Workman, Eric Walter.  
Wright, John Edwin.

TRANSFERS.

*Associate Member to Member.*

Ambrose, Ernest. Macleod, David Macfarlane.  
Frisby, William. Thomas, Sydney Warren.  
Grant, Archibald Ernest. Watson, Charles George.

*Associate to Associate Member.*

Vivian, Gerald Herbert E.

*Graduate to Associate Member.*

Greenhalgh, Edward.

*Student to Associate Member.*

Huntley, Charles Gordon. Scott, Gilbert James.  
Leak, Basil Widenham. Tufnell, Cecil Parr.  
Mann, Frank Harris. Walsh, Basil Percival K.  
Ramsey, Arthur George. Williams, Humphrey, B.Sc.  
B.Sc. (Eng.). (Tech.).  
Ross, John Douglas.

*Student to Graduate.*

Damania, Ishwarlal Bhogilal. Pallot, Arthur Charles  
Livesley, Robert Edwin. Lieut., R.E. (T.).  
B.Sc. (Tech.). Paul, Bangsidhari.  
Mowdawalla, Framroze Nusserwanji, M.A., B.Sc.

A paper by Mr. H. H. Harrison, Associate Member, entitled "The Principles of Modern Printing Telegraphy" (see page 309), was read and discussed, and the meeting adjourned at 9.55 p.m.

## INSTITUTION NOTES.

## REWARDS FOR SERVICE IN THE FIELD.

## Companion of the Bath.

Chambers, Lieut.-Colonel J. C.	West Riding Divisional A.S.C.	Member
Stuart, Brig.-General A. M.	Director of Works	Member

## Distinguished Service Order.

Chapple, Major F. J.	North Midland R.G.A.	Associate Member
Cowan, Major S. H.	Royal Engineers	Associate Member
Davidson, Captain A. E.	Royal Engineers	Associate Member
Leaf, Captain H. M.	Royal Marine Light Infantry	Member

## Victoria Cross.

Robinson, Lieut.-Comm. E. G.	Royal Navy	Associate Member
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"Lieutenant-Commander Robinson on the 26th February, 1915, (at Gallipoli) advanced alone, under heavy fire, into an enemy's gun position, which might well have been occupied, and destroying a 4-in. gun, returned to his party for another charge with which the second gun was destroyed. Lieutenant-Commander Robinson would not allow members of his demolition party to accompany him, as their white uniforms rendered them very conspicuous. Lieutenant-Commander Robinson took part in four attacks on the mine fields always under heavy fire."—*London Gazette*, 16, 18 August, 1915.

## Military Cross.

Goulden, 2nd Lieut. C. H.	Royal Garrison Artillery	Associate Member
Groom, Lieutenant H. R. L.	Royal Warwickshire Regt.	Graduate
Gwyther, Lieutenant H. J.	Manchester Regt.	Student
Lefroy, Captain H. P. T.	Royal Engineers	Associate Member
Massie, Lieutenant I. W.	Royal Engineers	Associate Member
Podmore, Lieutenant A.	Royal Engineers	Associate Member
Sherwell, 2nd Lieut. O. W.	Royal Field Artillery	Student
Tabor, Lieutenant A. R.	Royal Field Artillery	Student
Williamson, 2nd Lieut G. W.	3rd Manchester Regt.	Associate Member

## Distinguished Service Cross.

Boissier, Lieutenant E. G.	Royal Naval Division	Associate Member
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## Distinguished Conduct Medal.

Doig, Private A. M.	1/6th Manchester Regt.	Associate Member
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"For conspicuous gallantry and initiative on the 4th June, 1915, on the Gallipoli Peninsula. Taking six men with him

he captured a trench, thereby bringing fire to bear on the enemy, and repelling a counter attack. It was due to his action that the trench was not only taken but successfully held."—*London Gazette*, 15 September, 1915.

Wood, Private P. J.	18th London Regt.	Student
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"For conspicuous gallantry on 25th May, 1915, at Givenchy. When the communication between the Keep and Battalion Headquarters had been severed, he went out, during a lull in the bombardment, and proceeded to carry out repairs. The bombardment recommenced at once but he remained out about half an hour and completed the work."—*London Gazette*, 5 August, 1915.

Saunders, Corporal C. W.	New Zealand Engineers	Graduate
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## Distinguished Service Medal.

Murray, Sapper J. H.	Divisional Engineers, R.N.D.	Associate Member
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## Mentioned in Dispatches.

Bicknell, Lieutenant C. R.	Royal Garrison Artillery	Student
Casson, Captain W. Cottrell, Commander W. H.	London Regt. R.N.V.R.	Member Associate
Damant, Sapper E. L.	Divisional Engineers, R.N.D.	Student
Downes, Lieutenant H. L.	Liverpool Regt.	Associate
Edmonds, Lieutenant C. H. W.	Royal Engineers	Associate Member
Hann, Petty Officer C. S.	Hawke Batt., R.N.D.	Associate Member
Hart, Lieutenant L. V.	Royal Engineers	Student
Iles, Major F. A.	Royal Engineers	Associate Member
Knox, Major G. S.	Royal Engineers	Associate Member
Lefroy, Captain H. P. T.	Royal Engineers	Associate Member
Olver, Captain G. T. W.	Royal Engineers	Member
Smith, Captain T. V.	Royal Flying Corps	Associate Member
Spittle, Major G. H.	Divisional Engineers, R.N.D.	Associate Member
Stuart, Brig. General A. M., C.B.	Director of Works	Member
Tuppen, Lieutenant H. R.	Army Service Corps	Student
Williams, 2nd Lieut. R. A.	Royal Engineers	Associate Member

## MEMBERS ON MILITARY SERVICE.

## PROMOTIONS, TRANSFERS, ETC.

## MEMBERS.

<i>Name.</i>	<i>Corps, etc.</i>	<i>Rank.</i>
Carter, W. L.	Royal Engineers	Lieutenant
Cirelugh, S. V.	Army Service Corps	Captain
Harrison, H. T.	R.N.V.R.	Lieutenant
Leaf, H. M.	Royal Marine Light Infantry	Captain
Marshall, W. H. U.	Dorset (Fortress) R.E.	Captain
Piggott, R. E. P., C.I.E.	Suffolk Regt.	Lieut.-Col.
Pragnell, N. W.	R.N.V.R.	Lieutenant
Roose, F. O. J.	Royal Garrison Artillery	Captain
Wayne-Morgan, J.	Glamorgan (Fortress) R.E.	Major
Wraith, H. O.	Royal Engineers	Major

## ASSOCIATE MEMBERS.

†Battye, B. C.	Royal Engineers	Bt. Maj.
Benson, H. K.	Glamorgan (Fortress) R.E.	Lieutenant
Brown, A. Whit-	Royal Flying Corps	2nd Lieut.
Brown, G. J. L.	Lowland R.G.A.	2nd Lieut.
Brown, W. F.	Royal Engineers	Captain
Chapple, F. J.	North Midland R.G.A.	Major
Clarke, F. C.	London Electrical Engineers, R.E.	Captain
Clausen, H.	R.N.V.R.	Lieutenant
Cope, H. A.	London Electrical Engineers, R.E.	Captain
Digby, W. P.	London Electrical Engineers, R.E.	Captain
Dodds, J. W.	Northern Cyclist Batt.	Captain
Dunsheath, P.	Royal Engineers	Lieutenant
French, The Hon. E. Fulke	Divisional Engineers, R.N.D.	Farrier-Sergt
Gibson, J. S.	9th Bedfordshire Regt.	2nd Lieut.
Goolding, C. L.	London Electrical Engineers, R.E.	Lance-Corpl.
Grover, E. E.	14th Northumberland Fusiliers	Captain
Hann, C. S.	Hawke Batt., R.N.D.	Petty Officer
Harrison, N.	South African Engineers, Overseas Force	Major
Hawthorn, H. F.	London Electrical Engineers, R.E.	Captain
Hoggett, F. R.	10th Royal West Surrey Regt.	2nd Lieut.
Holland, H. N.	Army Service Corps	Captain
Hunter, E. B.	London Electrical Engineers, R.E.	Captain
Hutton, J. C.	6th South Staffordshire Regt.	Qmr.-Sergt.
James, J. G.	29th Royal Fusiliers	2nd Lieut.
Kirkby, H. McK.	Army Ordnance Dept.	Lieutenant
Langdon, W. C. C.	Royal Garrison Artillery	2nd Lieut.
Laurie, D. S.	Royal Engineers	Lieutenant
Leslie, R. C.	King's Own Scottish Borderers	2nd Lieut.
Long, R. F.	Royal Field Artillery	2nd Lieut.
McCarthy, A. J. P.	Royal Engineers	2nd Lieut.
Mann, T. S. L.	Westminster Dragoons Yeo- manry	Trooper
Mathews, S.	London Electrical Engineers, R.E.	Lieutenant
Merrett, W. H.	London Electrical Engineers, R.E.	Major
Miller, N.	Divisional Engineers, R.N.D.	Lieutenant
Milliken, R. C.	London Electrical Engineers, R.E.	Lieutenant

## ASSOCIATE MEMBERS—continued.

<i>Name.</i>	<i>Corps, etc.</i>	<i>Rank.</i>
Milnes, G. C.	5th Royal Lancaster Regt.	Captain
Moore, B. J.	Royal Flying Corps	2nd Lieut.
Morrow, H. E.	Divisional Engineers, R.N.D.	Captain
Mulliner, A. M.	9th Royal West Surrey Regt.	2nd Lieut.
Paton, G.	Army Ordnance Dept.	Lieutenant
Peter, B. H.	Royal Engineers	Lieutenant
Porter, A. R. Z.	Queen's Westminster Rifles	Captain
Preston, E. B. C.	57th Wilde's Rifles	2nd Lieut.
Reed, H. K.	London Electrical Engineers, R.E.	2nd Corpl.
Rich, T.	London Electrical Engineers, R.E.	Major
Robertson, A. M.	Dundee (Fortress) R.E.	Captain
Robertson, H.	Royal Field Artillery (T.F.)	2nd Lieut.
*Robinson, E. G.	Royal Navy	Commander
Rogers, W. R.	Royal Navy	Warrant Officer
Sanders, H. R.	25th London Regt.	2nd Lieut.
Slack, D. H.	Kent (Fortress) R.E.	Captain
Smith, A. P.	4th Argyll and Sutherland Highlanders	Captain
Smith, B. H.	Divisional Engineers, R.N.D.	Lieutenant
Smith, T. V.	Royal Flying Corps	Captain
Stanier, H. D.	Royal Engineers	2nd Lieut.
Stewart, W. D.	Royal Engineers	2nd Lieut.
Stiell, E. J.	Royal Engineers	Lieutenant
Sykes, G.	Royal Naval Air Service	Lieutenant
Talbot, W. A.	Divisional Engineers, R.N.D.	Sergeant
Taylor, C. A.	Army Ordnance Dept.	Lieutenant
Toogood, H. de C.	Royal Engineers	Captain
Turner, H. E.	East Riding R.G.A.	2nd Lieut.
Unwin, F. R.	1st London Divisional R.E.	Lieutenant
Vines, C. E.	Royal Garrison Artillery	Major
Watson, A. G.	Divisional Engineers, R.N.D.	Lieutenant
Webb-Bowen, H.	London Electrical Engineers, R.E.	Major
Williams, E.	3/1st London Divisional R.E.	2nd Lieut.
Wilson, J. L.	East Lancashire R.E.	Lieutenant
Wilson, W. S.	Durham (Fortress) R.E.	Captain
Wood, A. L.	15th Lancashire Fusiliers	Captain
Wood, E. L.	2/7th Gordon Highlanders	2nd Lieut.

## ASSOCIATE.

Hughman, K. W.	9th Middlesex Regt.	Captain
----------------	---------------------	---------

## GRADUATES.

Bowater, T. D. B.	Westminster Dragoons Yeo- manry	Captain
Bowers, E. G.	11th Northumberland Fusiliers	2nd Lieut.
Burnett, F. E.	East Riding R.E.	2nd Lieut.
Cater, F. L.	Army Service Corps	Sergeant
Grice, P.	North Staffordshire Regt.	2nd Lieut.
Hume-Williams, R.	Army Service Corps	Lieutenant
E.		
Leggett, B. J.	Royal Engineers	2nd Lieut.
Owen, R. E. L.	Royal Garrison Artillery	Lieutenant
Pells, E. A.	1st London Divisional R.E.	Major
Reay, G. H. N.	Royal Engineers	Captain

## STUDENTS.

Baker, H. G.	3/4th Gloucestershire Regt.	Lieutenant
Baxendell, L. W. E.	Divisional Engineers, R.N.D.	Corporal
Bell, H. G.	Royal Engineers	2nd Lieut.
Bicknell, C. R.	Royal Garrison Artillery	Lieutenant

\* See vol. 53, pp. 106, 126, 388, and 387; and vol. 54, p. 121.

† For service in the next.

\* For service in the field.

<i>Name</i>	<i>Corps, etc.</i>	<i>Rank.</i>
Brazel, C. H.	Royal Engineers	Lieutenant
Broadwood, L.	Royal Engineers	2nd Lieut.
A. T.		
Brent, N. B.	Royal Engineers	2nd Lieut.
Canton, G. D.	Army Service Corps	2nd Lieut.
Chadwick, E. L.	7th Royal Warwickshire Regt.	2nd Lieut.
Dawson, G. G.	Royal Naval Air Service	Flight Sub-Lieut.
Dixon, T. A. F.	Royal Engineers	2nd Lieut.
Edminson, E.	10th North Staffordshire Regt.	2nd Lieut.
Finnis, A. H.	25th Royal Fusiliers	Private
Furnival, J. M.	Royal Flying Corps	2nd Lieut.
Goble, F.	London Electrical Engineers, R.E.	Corporal
Hall, T. H.	Royal Garrison Artillery	Lieutenant
Havward, F. H.	R.N.V.R.	Lieutenant
Huntley, C. G.	Tyne Electrical Engineers, R.E.	2nd Lieut.
Jackson, Forbes	Divisional Engineers, R.N.D.	Lieutenant
Jackson, H. Y. V.	Royal Engineers	2nd Lieut.
Kilby, J. W.	Kent (Fortress) R.E.	2nd Lieut.
McDougald, L. A.	Royal Flying Corps	2nd Lieut.
Maguire, C. E.	Royal Anglesey R.E.	2nd Lieut.
Marx, S.	Royal Field Artillery	Lieutenant
Orme, B. R.	Wessex Divisional R.E.	2nd Lieut.
Pallot, A. C.	Hampshire (Fortress) R.E.	Lieutenant
Prince, G. R. D.	Kent (Fortress) R.E.	Captain
Protheroe, E. L. M.	Royal Field Artillery	2nd Lieut.
Protheroe, R. N. L.	Royal Field Artillery	2nd Lieut.
Reeves, W. A.	9th East Surrey Regt.	2nd Lieut.
Riley, H.	Royal Engineers	2nd Lieut.
Rodwell, J. T.	Royal Flying Corps	2nd Lieut.
Sadler, C. W. C.	Royal Engineers	Lance-Corpl.
Searle, A. M.	Royal Engineers	2nd Lieut.
Shaw, C. G.	2nd London Divisional R.E.	2nd Lieut.
Sherwell, O. W.	Royal Field Artillery	Lieutenant
Shuter, E. J.	Royal Marines	2nd Lieut.
Solomon, T. H.	Divisional Engineers, R.N.D.	Sapper
Stoneham, C. D.	Royal Engineers	Lieutenant
Trouton, D. G.	Royal Field Artillery	Lieutenant
Wilson, T. P.	East Lancashire A.S.C.	2nd Lieut.
Woolley, T. G.	East Lancashire Divisional R.E.	Captain

### LONDON ELECTRICAL ENGINEERS.

The Secretary has received the following information from the Officer Commanding the London Electrical Engineers:—

There are still vacancies for qualified electrical and mechanical engineers in the London Electrical Engineers, which are a unit of the Royal Engineers (Territorial Force).

The technical work of the Corps comprises the running and maintenance of searchlights and electrical generating plant used in connection with the coast defences and

anti-aircraft guns, telephone systems for communication with directing stations, and such other technical work at home and overseas for which men having electrical and mechanical experience are specially required.

The terms of enlistment are those laid down for the Territorial Force, service being for the duration of the war. In addition to regimental pay, engineer pay is granted according to technical proficiency and length of service, as well as the usual separation allowance or allowance to dependents.

If accepted by the Commanding Officer, recruits can be transferred from the groups under Lord Derby's Reserve "B," provided that their medical examination passed them as fit for service overseas and that the proclamation calling their group up for service has not been posted. Once this proclamation has been made there may be little chance of their getting into a technical unit.

Both at home and abroad the Corps is doing valuable work which only men having technical knowledge and experience can accomplish satisfactorily.

Applications should be addressed to the Commanding Officer, 46 Regency Street, Westminster, London, S.W.

### MEMBERS OF ENEMY NATIONALITY OR ORIGIN.

The Council have passed the following resolution:—

"The Council are of opinion that Clause 41 of the Articles of Association provides sufficient means for the expulsion of undesirable persons (whether alien enemies or not) from the Institution, consistently with making the thorough investigation of the circumstances of each case which is essential in order to avoid the risk of doing grave injustice to individuals."

The Council have also under consideration the question whether the Institution should obtain further powers for the expulsion of alien enemies.

### BEIT SCHOLARSHIPS FOR SCIENTIFIC RESEARCH.

The third election of Fellows will take place on or about the 15th July, 1916. The Fellowships, of which not more than three will be awarded at this election, will be tenable at the Imperial College of Science and Technology, South Kensington, and will each be of the annual value of £150. The tenure of a Fellowship is for one year, but it may be extended by the Trustees for a further period not exceeding one year. Candidates must be under 25 years of age on the date of election. Applications will be received up to the 15th April, 1916, and must be made out on special forms, which, together with any other particulars in respect of the Fellowships, may be obtained, by letter only, addressed to The Rector, Imperial College of Science and Technology, South Kensington, London, S.W.

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## THE PRINCIPLES OF MODERN PRINTING TELEGRAPHY.

By H. H. HARRISON, Associate Member.

(Paper received 1 November, 1915; read before THE INSTITUTION 20 January, before the MANCHESTER LOCAL SECTION 25 January, and before the SCOTTISH LOCAL SECTION 8 February, 1916.)

### PART I.

Fundamental principles. Elementary forms of type-printing telegraph. Step-by-step printing telegraph. Isochronous free-running type-wheel printing telegraph. Inversion devices. The 5-unit code. The locked keyboard. Mechanical storage transmitter. Tape-perforator mechanisms. Automatic stop and start.

The printing telegraph is one of the oldest methods of communication employed since telegraphy became a public utility. Over a period of about 80 years innumerable systems have been invented, but up to 1900 only two can be said to have achieved permanent success: the Hughes, invented by the late David Hughes as far back as



FIG. 1.—Elements of a telegraph installation.  
Transmission in one direction only.

1854, and the multiple system of Baudot, first introduced in 1874. From this latter date onward, high-capacity printing-telegraph systems have been proposed, but they have all possessed some fundamental defect. To Donald Murray must be given the credit of first clearly laying down the broad principles on which a printing telegraph should be designed. His paper, read before the Institution in February 1905,\* will always be the classic on this subject and, in addition, is a model of style, unusual in a paper of a technical character.

One of the facts which forcibly strike the student of present-day printing telegraphy is the convergence of nearly all inventors towards the adoption of the 5-unit

alphabet. As a result, there is close similarity between the devices employed in competing systems. This is not surprising, for, as has been pointed out by Murray, given an alphabet then the design of instruments produced to use it must proceed on certain lines.

Reduced to its simplest terms, a telegraph installation will be found to comprise a circuit-making device or transmitter K (Fig. 1), a battery B, and an electromagnetic receiver M, all connected in series through the line L. The transmitter takes the form of a lever, adapted, when depressed, to connect an earthed battery to the line. This

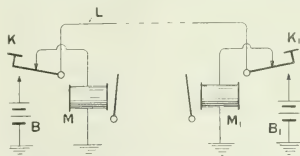


FIG. 2.—Elementary telegraph installation, with automatic and instant reversal of direction of transmission.

is the familiar Morse key which has been in use for over 60 years. Usually transmission is desired in either direction at will, and the lever is so arranged that in the normal position (Fig. 2) the line at both ends is connected to earth through the coils of the receiving electromagnet. So arranged, it is the typical installation of the simplex Morse sounder circuit employed all over the world. It is not, however, suitable for any but short lines, or those which are free from inductive and other disturbances. The spaces between signal elements are intervals of no current or zero units, and during these times the receiving instruments are liable to be interfered with by any disturbing currents to which the circuit may be exposed. This tendency may be largely overcome by employing polarized

\* D. MURRAY: "Setting Type by Telegraph," *Journal I.E.E.*, Vol. 54, p. 555, 1905.

receivers and using two directions of current, as shown in Fig. 3. The direction of transmission is now no longer automatically reversible, and switches  $S$  and  $S_1$  have to be operated.

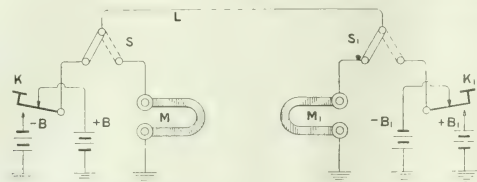


FIG. 3.—Elementary telegraph installation using polarized receivers and double-current transmitting keys.

A further advantage of this double-current working lies in the fact that the polarized instrument is much more sensitive than the non-polarized spring-controlled apparatus; and also that the controlling force is always equal in effect to the disturbing force, provided that the instrument is given no bias. Consequently, with varying line conditions such as would affect the value of the received

current, no printing telegraph can prove successful on long lines if worked with current differences, owing not only to the diminished operating margin but also to the dangerous zero-current intervals. This fact has been emphasized by Donald Murray and is common knowledge to telegraph engineers; but printing telegraphs continue to be invented employing zero units and even using two strengths of current. With regard to zero units, an important exception has to be made. The long single-core ocean cable, far removed from any possible electrical disturbances of a rapidly varying character, can, and in fact is, worked by alphabets using the zero unit.

All printing telegraphs will be found to contain in a

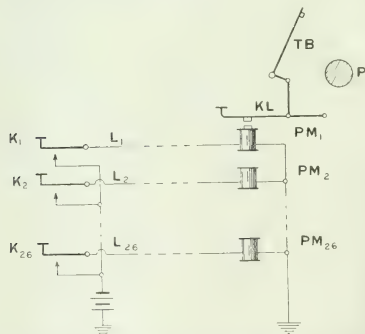


FIG. 4.—Elementary form of type-printing telegraph using line wires equal in number to the number of characters.

current, the receiver will work without readjustment over a wide range. The same results are not realized with a spring-controlled instrument, since for a given spring tension the current must not vary in the least if the controlling and disturbing forces are to remain equal. Theoretically, the forces due to the spring tension should be equal to half the pull of the received current on the relay armature. When this adjustment is made, the two forces—the controlling and disturbing forces—will be equal. If the received current falls off owing to failing line insulation, this equality is upset, but the instrument is still capable

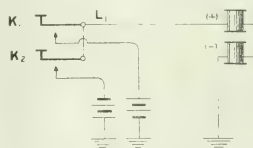


FIG. 5.—Elementary form of type-printing telegraph using polarized selective means to reduce the number of line wires.

more or less specialized form the transmitting lever capable of assuming two positions, the receiving electromagnet or magnets, the two earthed transmitting batteries at each end of the line, and in most cases, but not all, the switches for reversing the direction of transmission.

An elementary form of printing telegraph can be formed by taking a number of wires equal to the number of characters and connecting to these a similar number of character levers. Each line is connected to earth at the receiving end through electromagnets controlling character key levers of an ordinary typewriter (Fig. 4). By adopting both positive and negative signalling impulses, the receiving electromagnets may be divided into two groups if suitably polarized, and the number of wires required, compared with the previous case, is halved (Fig. 5).

Either of these systems is of course impracticable owing to the line material involved, but by abolishing the single signalling impulses and making permutations of positive, negative, and zero units, the line wires can be considerably reduced in number.

With any line wire there are three possible variations: positive or negative current flowing, or zero current. By taking the three variations possible in one wire and combining them with three similar variations in a second wire, nine signals can be formed, and adding the variations of a

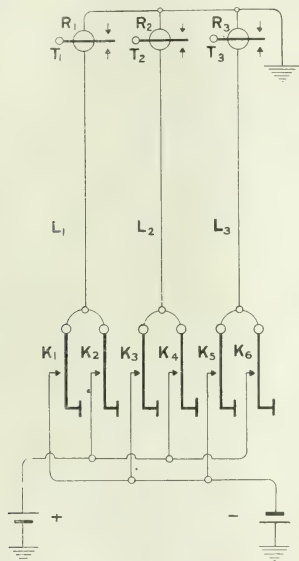


FIG. 6.—Application of principle of permutation to transmission of a comparatively large number of signals over a small number of line wires.

third wire, a total of 27 signals is possible. Actually one of the 27 signals cannot be used as it consists of a zero unit in each line wire, and this is the normal or non-operative condition, so that generally the number of signals possible is  $V^n - 1$ , where  $n$  = the number of lines available, and  $V$  = the number of variations furnished by each wire. For three wires the total number of signals is given by  $3^3 - 1 = 26$ , which just suffices for the alphabet.

A telegraph on this plan is illustrated in the next figure, in which six keys are connected in three pairs to a similar number of lines. By suitably depressing the keys, current permutations are set up in accordance with the table given

in Fig. 7. The currents are arranged to set the armatures of three polarized relays at the distant end, the armatures being normally in a neutral or mid position. If a positive or negative current traverses the relay coil, the armature moves to the right or left as the case may be. The permutations set up at the transmitting keyboard are thus copied at the receiving relays by the deflection of their armatures. A further mechanism is required to translate the complex signal represented by the arrangement of the armatures into the simple signal, the printed character. One method of effecting the translation consists of a series of six electromagnets (Fig. 8) selectively operated by the receiving relays. Each electromagnet controls a rod carrying bridging contacts or switches, and for any given re-arrangement of the rods from their normal position as indicated, a

		1	2	3
1	A	+	○	○
2	B	+	+	+
3	C	+	+	+
4	D	+	+	+
5	E	+	+	+
6	F	+	+	+
7	G	+	+	+
8	H	+	+	+
9	I	+	+	+
10	J	+	+	+
11	K	+	+	+
12	L	+	+	+
13	M	+	+	+
14	N	+	+	+
15	O	+	+	+
16	P	+	+	+
17	Q	+	+	+
18	R	+	+	+
19	S	+	+	+
20	T	+	+	+
21	U	+	+	+
22	V	+	+	+
23	W	+	+	+
24	X	+	+	+
25	Y	+	+	+
26	Z	+	+	+

FIG. 7.—Illustrating the current permutations set up and transmitted by the arrangement of Fig. 6.

circuit is completed for the local or printing battery K M B, through one and one only of the character key magnets K M shown on the right-hand side of the diagram.

A printing telegraph on the general lines described above was proposed by Highton in 1848 and is the first instance on record of the suggestion of the modern type-bar typewriter with circular platen. In this system the objectionable zero unit occurs, which rules it out so far as its employment on other than very short land lines is concerned, but it has been suggested by Murray to use the alphabet for ocean-cable printing-telegraphy. The system is also extravagant with respect to line material.

It will be seen from the foregoing that the transmission and reception of signals is effected by the displacement of a transmitting lever, which is copied at the receiving end of the line by the displacement of an electromagnetically controlled lever. If we wish to use one line wire only,

there are three methods of translating such elementary signals into type-printed characters:—

- (1) By the number of signal elements ;
- (2) By the duration of the signal elements ;
- (3) By the moment of their appearance.

The first method assigns one impulse to the letter A, two to the letter B, three to letter C, and 26 to the letter Z. This is the principle on which step-by-step printing telegraphs depend for their action, and is theoretically set out in Fig. 9. The transmitter consists of a barrel B driven by a motor M through a friction drive F D. A number of

this relay alternately closes the circuit of the two escapement magnets E M, which allow the escapement wheel to move round tooth by tooth. This wheel is mounted on a shaft carrying the type-wheel T W, the combination being constrained to rotate by a slipping drive not shown. So long as the barrel continues to revolve, the type-wheel follows its movements, keeping in step by the method of control outlined above. In series with both the escapement magnets is a printing magnet P M, which is relatively slow-acting and is unaffected by the stepping impulses. When one of the impulses is prolonged by the momentary stoppage of the transmitter barrel, the printing magnet is

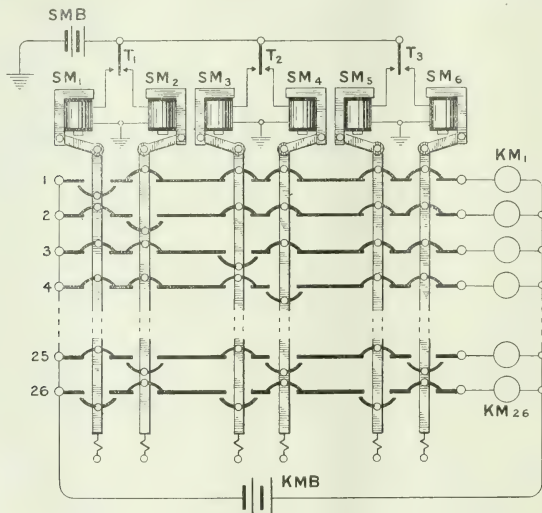


FIG. 8.—Method of translating line signals of Figs. 6 and 7 into printed characters.

pins P on the barrel form a helix and when any one of the keys of the keyboard K B is depressed, its far end rises into the path of the corresponding pin and stops the barrel as long as the key and pin are in contact. The period of the revolution at which this stoppage occurs depends upon the key depressed. At the right-hand end of the barrel, a crown-wheel commutator is arranged to send alternating currents to line, 14 periods per revolution of the barrel. When the barrel revolves continuously, the alternating currents step round the type-wheel at the distant station, and a stoppage of the barrel by a character key prolongs the impulse, positive or negative, at that moment going to line, and effects printing in a manner to be described. At the receiving end of the line the alternating currents pass through a polarized relay L R to earth. The armature of

energized and forces the paper tape against the type-wheel. This wheel is kept inked by a roller, not shown, and the selected letter is imprinted on the tape.

The second method uses two durations of current, a short impulse and one three times as long, and the various signals are differentiated by combinations of the two elementary signals. The Morse code is an example of this procedure. Only one practicable and successful printing telegraph—the Creed—uses this alphabet.

Fig. 10 illustrates a development of the step-by-step system, and represents, theoretically, the well-known Hughes printing telegraph.

At the transmitting end, a contact-brush arm B is kept in continuous rotation. It makes contact with the solid ring shown and also, in turn, with a number of contacts each

connected to character keys of which only one, K, is illustrated. Signals pass to line accordingly as keys are depressed or not. The number of segmental contacts is equal to the number of character keys, and the whole transmitting mechanism is simply a device for dividing very precisely the time of a revolution. The significance of a signal depends upon the moment or interval of time in which it occurs during a revolution.

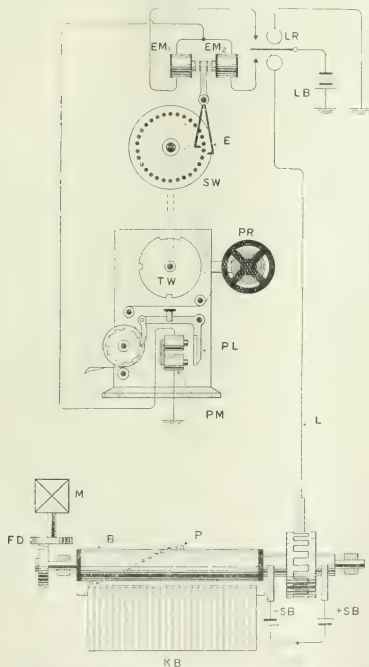


FIG. 9.—Principle of the step-by-step type printing telegraph.

At the receiving end of the line, a free-running type-wheel TW, synchronized with the contact-brush arm B by methods not shown, is divided at its circumference into as many type faces as there are transmitting intervals on the collector C. Solid on the same shaft as the type-wheel is a feed cam FC which engages with the paper-feed ratchet mechanism FR, and feeds the paper tape forward one letter space after printing. In the diagram only one letter per revolution is supposed to be printed, although actually in the Hughes only four letter spaces need intervene

between the printing of successive letters. As a signal impulse is received over the line, it excites the printing magnet P M, and the printing hammer P H forces the paper against the type-wheel, effecting printing of the letter which at that moment is in the printing position.

In both the Hughes and the step-by-step systems the signalling impulses are equal in duration, but the spacing between letters in respect to time is variable and depends upon the preceding signal. In both cases, signals are differentiated by time; a certain period is taken and subdivided into as many parts as the required number of characters, and each interval corresponds to a given letter or character. Highton's telegraph does not depend upon time as a means of differentiation; the signals remain space signals at both ends of the wire. A given permutation may be set up indefinitely; and the corresponding type bar, and only that particular bar, will be actuated.

Also, the two systems using time signals have used rotating collectors at the transmitting end by which the signals are impressed on the line, and a revolving type-wheel at the receiving end. The transmitting and receiving organs are dissimilar. If a typewriter is used as a printer, then a transmitting collector is used as before, and a similar organ has also to be employed at the receiving end to perform the inverse function, viz. to distribute the incoming signals to the appropriate character key levers. The arrangement is indicated in Fig. 11. Two circular contact discs D, D<sub>2</sub>, are surrounded by segmental contacts connected at the transmitting ends to character keys, and at the receiving end to electromagnets controlling the key levers C K L of the typewriter. Contact-brush arms at both ends rotate synchronously and connect the rings D, D<sub>2</sub>, with the segments in turn. Rings D, D<sub>2</sub>, are connected together by the line wire. The time taken for a complete revolution, if divided into 26 intervals, only provides for the alphabet, and to print numerals and punctuation signs further subdivision is necessary. There must be a minimum length of contact for a given line, and the greater the number of contacts to be swept over per revolution the lower is the speed of transmission. The number of segments may be reduced by using both positive and negative impulses, as described in connection with Fig. 5. The number of segments to deal with the alphabet and also with secondary signals may also be kept down to  $26 + 2 = 28$ , with ability to print 52 characters by employing mechanism analogous to the shift-case key of the ordinary typewriter. A number of such devices are illustrated in Fig. 12. Method A employs two type-wheels adapted to be moved axially on the type-wheel shaft supporting them. One type-wheel carries the alphabet, and the other the secondary characters, and printing is effected from one or the other accordingly as it is brought over the printing point P. The two signals extra to the 26 are employed to shift the wheels backwards and forwards. A single wheel may be employed with the two groups of characters placed alternately round the periphery (see diagram B). The shift from one set of characters to the other is accomplished by a movement through an angle equal to the pitch of the type faces.

In both instances, shift of case is accomplished at two blank portions of the type-wheels, so that the paper is fed forward without an impression. By either of these variations of the same means, 52 characters can be controlled

with 28 time intervals. Diagram C shows how shift of case is accomplished on many of the commercial forms of typewriter. Two type faces are mounted on each type

case of an unequal-letter alphabet like the Morse, and this again saves line time.

It has been pointed out that zero units are inadmissible

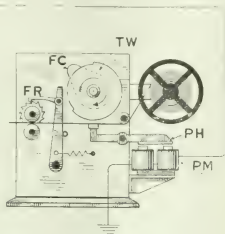
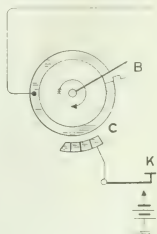


FIG. 10.—Principle of Hughes type-printing telegraph.

bar at distances  $R_1$  and  $R_2$  from the type-bar pivot. The printing point on the platen is on the vertical centre-line, and by moving the platen P backwards and forwards one or other of the type-faces effects printing. In diagram D, the shift of case is secured by vertically moving the basket on which all the type bars are pivoted, the platen being immovable. In order that this vertical movement should not actuate the type bar, a bell-crank lever B C and links L and R L are interposed between the key lever K L and the type bar. In the diagram, printing is just about to take place. Murray has experimented with both shifts illustrated by diagrams C and D, and says that the basket shift

for any but the shortest lines, and have to be replaced by negative units if long-distance transmission is desired.

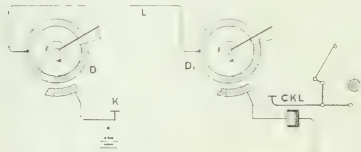


FIG. 11.—Selection of one of a number of printing elements by means of time signals over a single wire.

is to be preferred for printing telegraphy, as the type basket with the type bars is lighter than the usual solid platen and can therefore be operated more rapidly. By any of these variations it is possible to control 52 characters with only 28 time intervals, but by adopting rotary distributors and making permutations with three pairs of signalling keys, as in Highton's printer, we can reduce the time intervals per letter signal to three. The effect of this is to lower the time of transmission per letter and thus to raise the traffic-carrying capacity of the line. Further, every letter is now of equal length with regard to both time and space, and this has an important bearing on the design of apparatus, since any feed-motion device used takes equal steps and no differential gearing is necessary. Also, there is no space required between letters as in the

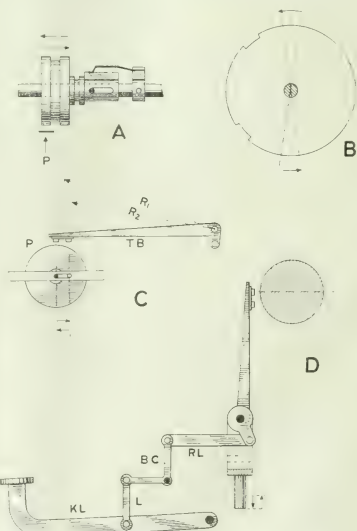


FIG. 12.—Inversion devices for type-wheel and type-bar printing mechanisms.

With this restriction, the number of permutations per lever of the Highton transmitter is now two, and the maximum number of signals which could be sent, is

$V^n - 1 = 7$ , while we have to provide for 28. The only possible way of increasing the number of signals is to use more transmitter levers and, of course, a correspondingly

inversion devices 62 characters may be controlled. The 5-unit alphabet is the shortest practicable for telegraphy; it is the alphabet that has been used in the wonderfully

### HUGHES . 126 UNITS.



### STEP-BY-STEP. 125 UNITS.



### MORSE . 69 UNITS.



### FIVE UNIT CODE. 35 UNITS.



FIG. 13.—Time comparison of telegraphic codes for the word "London."

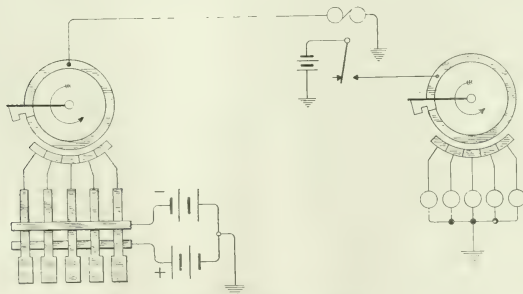


FIG. 14.—Elementary apparatus for sending letter-signal current permutations over a single line wire.

increased number of receiver levers.  $V$  is now 2, and to fulfil the required conditions,  $2^x - 1 = 28$ , from which  $X$  is found to be 4·8 or 5 levers. Five levers will furnish 31 primary signals, and by any of the previously described

successful Baudot printing telegraph, the Murray, and others; and Siemens and Halske, after spending years in developing a high-speed printing telegraph, have redesigned their apparatus to use the 5-unit alphabet.

The saving in line time with this alphabet, compared with the Hughes and the Morse, is graphically shown in Fig. 13.

The elementary mechanism by which the signal permutations for the 5-unit code may be set up, transmitted, and received, is diagrammatically illustrated by Fig. 14.

Two revolving contact-brush arms having the same angular velocity and phase, sweep over concentric metal conducting rings, the inner rings being continuous while the outer rings consist of segmental contacts. The brush arms at each end bridge the two concentric rings. At the transmitting end, the five signalling keys which normally rest against the upper or negative busbar are joined to five segments on the distributor as shown. If one or any number of these keys are depressed by the operator, they leave this bar and make contact with the positive bar, and as the revolving contact-brush rotates, it collects the current permutation set up at the keyboard and sweeps it

indication must be given to the operator when to set up a fresh letter, since it is obviously impossible to ascertain this by watching the revolving arm. It is also necessary that the setting of the keys should persist until the brush arm has swept over the entire five signalling segments.

An early method of accomplishing the two results is shown in Fig. 15, diagram A. Here each of the keys is provided with a locking latch L adapted to be caught by a pivoted rocking-frame RF, which is so constrained by a spring S that it normally tends to lock all the signalling keys. Directly coupled to the shaft carrying the contact-brush arm is a cam C, which during that portion of the revolution through angle  $\beta$  pushes the frame RF to the right, unlocking the keys and allowing the operator to set up a fresh permutation. This period is signalled to him by a hammer fixed on the rocking frame which taps a bell or other suitable device. This illustrates the well-known "cadence" signal of the Baudot printing telegraph, though

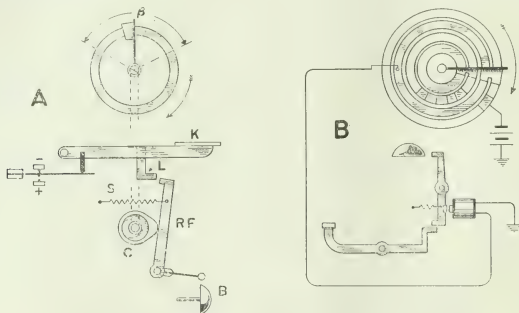


FIG. 15.—Examples of keyboard locking and cadence signal devices.

into the line. At the receiving end, the signalling impulses actuate a polarized relay, the positive impulses moving its armature to close a local circuit through the distributor to the five setting magnets. If at any moment the contact-brush arms are on corresponding segments, the particular receiving magnet will be actuated accordingly as the corresponding transmitting lever is depressed or not. Thus, by the employment of the intermediate mechanism of distributor and collector, the operator at the transmitting end can select any one of the setting magnets at the receiving end singly or in combination, and this with a single line wire. This result has been accomplished by the conversion of the space signals at the keyboard into time signals on the line, and their re-conversion into space signals as represented by the displacement of the armatures of the receiving magnets through the distributor at the receiving end of the line.

There is a very necessary condition to be met at the transmitting end of the line, viz. the signal permutations must have been set up before the contact-brush arm commences to sweep over the five transmitting contacts; and as this arm revolves at from 3 to 5 times per second, some

it may be remarked in passing that it did not originate with Baudot. After the permutation is set up, the keys are locked, thus preventing interference during transmission and also ensuring that the letter to be signalled remains set up until the contact-brush arm has passed over the collector segments.

The modern arrangement is identical in principle but different in detail, and is shown in Fig. 15, diagram B. The keyboard is unlocked electrically by contacts closed on the distributor. Such keyboards are termed by Murray "bound," the speed of transmission being fixed by the revolutions per minute of the contact-brush arm. The least stoppage on the part of the operator to sign and time a transmitted message or to decipher a badly written word, reduces the output, and experience has shown that this may amount to as much as 27 per cent, and with inexperienced operating even poorer results are attained. Improvement may be effected by using individual character keys, so that no mental effort is demanded from the operator other than the selection required in ordinary typing.

Such a transmitter, with one character key only shown,

is illustrated in Fig. 16, diagram A. This is arranged to use the Highton alphabet. Three pairs of sliding rods, 1 to 6, are kept in the normal position shown, by springs S. At their lower ends they are joined to bell-crank transmitter levers, pivoted on an insulated support F. The three line wires are connected to each pair of levers through the springs. Pins P are fixed on the rods so that the under surface of the key lever KL will engage these during its downward movement, and rock the bell-crank levers. The under surface of the key lever is of varying depth from the pivot to the finger button, in order to give all bell-cranks the same amount of rotation. As shown,

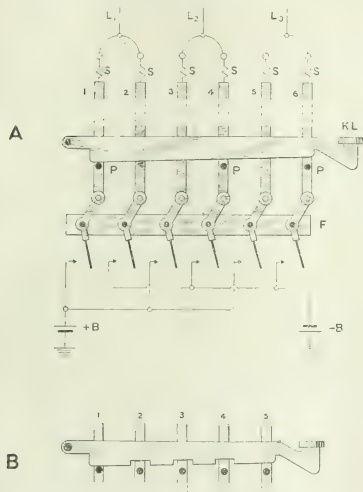


FIG. 16. Method of setting up current permutations by character-key levers.

the particular character key sends a positive current to line 1, a negative current to line 2, and a negative current to line 3. Diagram B shows an arrangement for the 5-unit code. Here a variation in the construction of the key lever is illustrated, pins being fixed on all the sliding bars, and the under surface of the key cut away where it is not desired to actuate a sliding bar. Keyboard transmitters of this type perform the inverse function to the translator at the receiving end, as they convert a simple signal, the mere depression of a key, into the complex signal represented by the current permutation assigned to the character which the key represents. Such transmitters relieve the operator to some extent of mental strain and manipulative exertion, but the "cadencing" has to be observed, and skill, additional to that of expert typing, is still necessary.

Moreover, the keyboard remains bound. A good typist will easily operate steadily at 50-60 words per minute, and the instantaneous rate will at times exceed this with favourable letter sequences. Now the maximum speed at which a manually-worked printing telegraph is run ranges from 30 to 45 words per minute (3 to 4.5 r.p.m. of the contact-brush arm), and if a reservoir for storing signal permutations as soon as they were set up by the operator were

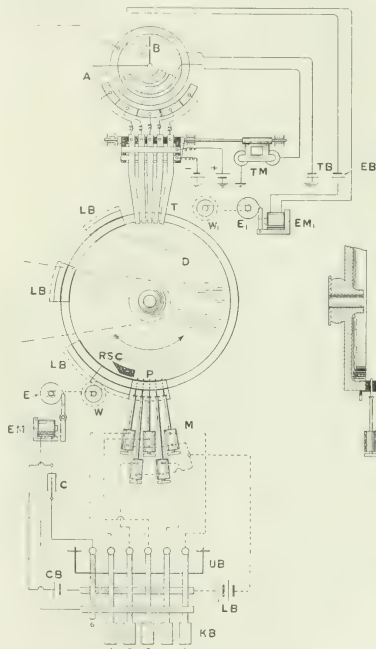


FIG. 17.—Mechanical signal-storage.

provided, advantage could be taken of the difference between the rate of setting up signals and their collection and transmission over the line. The keyboard would then be free, and the excess of operating over transmitting speed would counterbalance the effects of the stoppages before mentioned. The operation is then confined to the mental effort in selecting the appropriate character keys as in ordinary typewriting, no cadence has to be observed, and with operators trained to "touch-typing," so that their eyes remain on the "copy," manipulation tends to become as automatic as it is with the Morse key.

There are two ways in which this reservoir may be provided: (a) by a revolving drum fitted with pins set from the keyboard; and (b) by the use of a perforated tape. Kinematically the two mechanisms are identical. Fig. 17 sets out in a theoretical form a mechanical method of storage interposed between the keyboard and the transmitting distributor. D is a metal disc suitably supported and continuously rotated by a belt drive at a speed of about 3-4 revolutions per second. On the rim of the disc a number of metal blocks LB are placed, and if nothing interferes these are carried round with the disc by friction. Each block has five sliding pins P capable of being pushed inwards towards the centre of the disc by means of five electromagnets M. The pins are only shown in one of the blocks, but each block is provided with five pins, as shown in the block opposite the magnets M. The lower and outer edge of each block is provided with a segmental gear shown by dotted lines, and as they approach the setting position, the first block gears with a wheel W which is held stationary by a one-revolution escapement E controlled by the electromagnet EM. The disc continues to revolve and, the first letter block being held as described, the others are brought round and against it, the blocks accumulating on the left-hand side of the disc. In the illustration the process of accumulation is shown as commencing.

KB is a 5-key keyboard with signalling keys 1 to 5. By means of a universal bar UB, the operation of all or any of the signalling keys, operates a lever 6 closing a circuit for the battery CB to charge a condenser C. Simultaneously, the magnets M corresponding to those signalling keys which have been operated, are energized and push in the pins P. When the operator releases the keys, lever 6 forms a circuit for the discharge of the condenser through the escapement magnet EM, which attracts its armature, allowing the escapement E and with it the gear wheel W to be free for one complete revolution. For clearness the gear wheel has been drawn to the left of the letter block at the setting position, but it should actually be in gear with this block. When W is released as above described, the friction between the disc and the letter block carries the latter round so that W makes one revolution, when E is caught by the armature of EM. Thus the letter block which has just had a signal stored in it is carried round by the disc to the transmitting point and another letter block is brought to the setting point. Just before the letter blocks reach the setting point, they pass a resetting cam RSC, which pushes any pins that may have been operated on to their normal position ready to store a fresh signal. The letter blocks are carried round on the right until the first one reaches a gear wheel W<sub>1</sub>, which should be diametrically opposite the setting point but is drawn to the right of this for clearness. The transmitter T consists of five contact springs connected to five segments on the transmitting distributor. These springs are carried on a frame which is rocked by a magnet TM so that the springs press down on the disc D and encounter the storage pins if these have been pushed in. Where the spring meets a pin it is forced away from the negative busbar against which it normally rests and makes contact with the positive busbars, thus sending a positive current to line through the distributor. The transmitter springs are kept down during the whole period of a letter signal

by a circuit closed on the distributor through magnet TM and battery TB.

Just before the distributor contact-brush A commences to sweep over the transmitter segments, contact-brush B closes a circuit for battery E B through escapement magnet

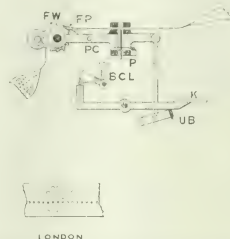


FIG. 18. Early form of perforator (Baudet).

E M<sub>1</sub>, releasing W<sub>1</sub> for one revolution and allowing the letter block next about to be acted upon to come to the transmitting point. Murray appears to have been the first to propose this sliding letter-block plan, and in 1906 he con-

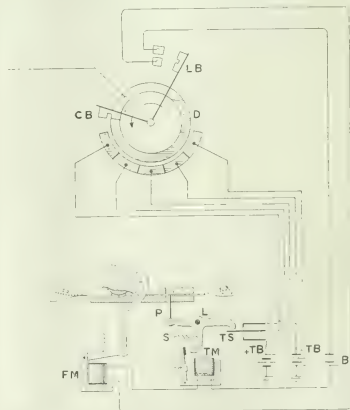


FIG. 19. Automatic transmitter controlled by signal tape and working with a rotary distributor.

structed for the British Post Office a storage transmitter on these lines; but although the general idea of the pin drum is quite old, no application of the many ingenious designs presented from time to time has been made. There is a distinct field for such transmitters, and indications are not wanting which point to their use to some extent in the near future.

The alternative method of signal storage involves two pieces of apparatus: the perforator and the transmitter. An elementary form of perforator due to Baudot is diagrammatically indicated in Fig. 18.

Five keys control a similar number of bell-crank levers BCL pivoted on a common rod. When the keys are depressed, their left-hand ends tilt the bell-cranks to the right. By means of a universal bar U B operated by all or any of the keys, a punch carriage P C is rocked through a small angle in a clockwise direction, and the punches encountering the heads of the tilted bell-cranks are pushed through the paper which is threaded through die blocks. The paper feed is accomplished by a ratchet wheel F W loose on a bar, on which the punch carriage is pivoted. During the rotation of the carriage to effect perforation a feed pawl F P, pivoted on the carriage, is rotated around the ratchet wheel, which is locked by a pawl not shown. On the return motion of the carriage the feed pawl moves the ratchet wheel through one

enter the holes under the action of springs S, and will so tilt the levers L as to depress their contact springs TS, thus connecting positive battery + TB to the corresponding distributor segment. Where the tape is unpunched, the pin P cannot rise, and the lever L corresponding to that pin remains in the normal position of the diagram. To the left of the transmitter a small roller with feed pins engages the centre row of holes in the tape, and the paper is fed forward intermittently letter by letter by the following circuit arrangements. Just before the contact brush CB of the distributor commences to engage the first of the five transmitting segments, a second brush, L B, bridges two contacts on the distributor and a circuit is closed for battery B through electromagnets T M and F M in series. T M is arranged to act just before F M, and by a universal bar on the end of its armature withdraws any pins P which may have entered holes in the tape. Immediately afterwards F M feeds the tape forward a letter space, presenting another set of letter holes to the pins L which now take

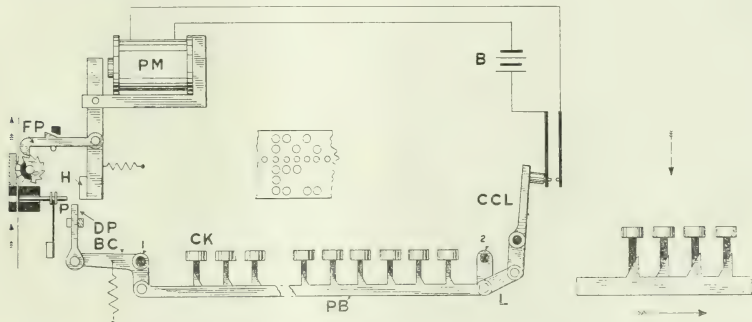


FIG. 20.—Method of operation of modern keyboard perforator.

tooth space. Attached to this wheel is a barrel with a row of pins which engage the centre row of holes in the tape. The small centre row of holes is seen in the diagram below the figure, and may be either produced before perforation or can be formed by the addition of a sixth or universal punch actuated when any of the signalling punches are put into operation.

Fig. 19 shows a form of automatic transmitter designed to use a perforated tape of the character shown in Fig. 16. D is the usual form of transmitting distributor, its five segments being connected to five contact springs TS which normally rest against other springs connected to the negative battery TB. The springs TS are controlled by the right-hand horizontal member of the levers L, all pivoted on a common pivot and each constrained to rotate slightly in a clockwise direction by springs S. The left-hand horizontal branch of L has small selector pins P jointed to it, and these enter the holes in a die plate through which the tape is threaded. If that portion of tape over the pins P has holes punched in it, the pins will

up new positions controlling contact-springs TS in readiness for the rotation of brush CB over the transmitting contacts of the distributor.

The modern perforator is provided with a typewriter pattern of keyboard with individual character keys, and the punches appropriate to a letter are selected and driven through the paper tape by the single action of the depression of one of the keys. Fig. 20 diagrammatically represents the general arrangement. Six parallel bars PB are jointed to rocking bars pivoted at 1 and 2 on the frame of the machine. The bars are provided with varying arrangements of saw teeth adapted to engage the under surface of the character-key levers CK. On the depression of a key a varying number of these bars are moved to the left. In doing so they rotate bell-crank levers BC and raise distance pieces DP between the hammer head H of a punch magnet PM. The hammer head can actuate the whole of the punches, provided that the distance pieces have all been selected, and only those punches the distance pieces of which have been interposed will be driven.

through the tape. A sixth or universal bar which is actuated when any key is operated ensures that the centre row of feed holes is punched; and also by the link L and

a cam surface on the back of the feed pawl coming up against a fixed stop on the frame of the machine.

The methods of selection possible in perforators of this

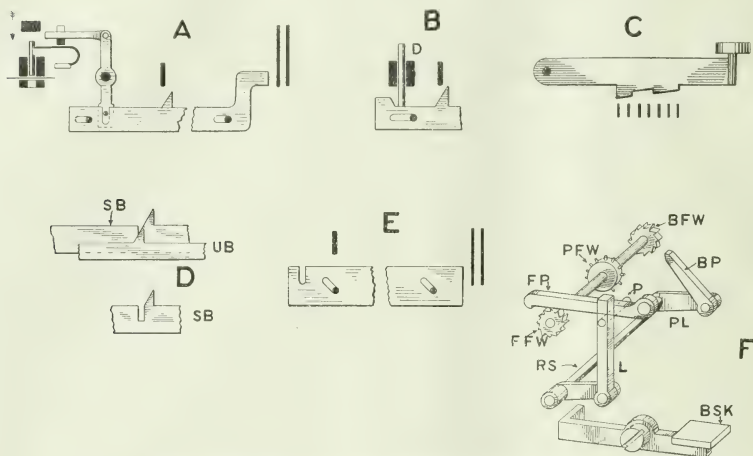


FIG. 21.—Various methods of selecting and actuating perforator punches. Also back-spacing device.

circuit-closing lever C C L it closes the circuit of battery B through the punch magnet. The armature of this magnet is spring-retracted, and on the return stroke it feeds the punched paper by means of the feed pawl F P, ratchet

class are very numerous; Fig. 21, diagram A, shows one variation. In diagram B the distance-piece D rests normally on the selector bar and is raised by a cam surface on the selector bar itself. C illustrates a method

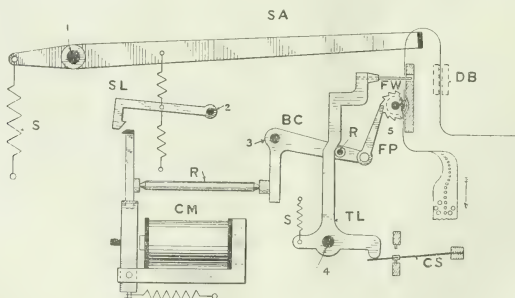


FIG. 22.—Murray automatic "stop and start" device.

wheel, and pin-feed wheel shown in the diagram. The punches are retracted by small leaf springs. This construction is due to Murray. Over-feeding is prevented by

by which no saw teeth are required on the selector bars, the under surface of the key levers being differentially slotted. D represents an arrangement in which the

punches selected are first set before the punch magnet is actuated. The selector bars SB have a small vertical slot from their top edge to a depth of half the height of the bar. In front of these a universal bar is placed, the saw teeth of which cover these slots. The distance-pieces are thus first assembled, and continued downward-movement of the character key locks them in position and then moves the universal bar to the right, closing the circuit of the punch magnet. E represents a selector bar with diagonal slots and supported on two pins. It is held in its normal position by a spring not shown. When depressed it moves downward and to the right, closing the contact springs of the punch magnet and actuating the punches by the mechanism shown in diagram A. This form of bar has been used in type-composing machines.

One of the modern requirements of a printing telegraph system, especially if of the page-printing type, is some means for invisibly correcting errors which may be punched in the transmitting tape. The operator is usually conscious immediately he or she has depressed the wrong character key, and this fact makes it possible for such correction to be made. If the receiving printer is arranged so that the signal represented by the whole five punched holes across the tape is inoperative in every way, then it is only necessary to pull back the tape and obliterate the incorrect letter or letters which may have been punched. This necessitates an arrangement similar to the back-spacing device of the modern typewriter.

A construction due to Murray is indicated in diagram F. A shaft carries the pin-feed wheel PFW and two ratchet wheels, one FFW for the normal forward-feed driven by the pawl FP in the manner shown in Fig. 20. The ratchet wheel BFW has its teeth set oppositely to that of FFW. On depressing the back-spacing key BSK, the link L with pin P raises FP clear of FFW, while, at the same time, motion is communicated through the rock-shaft RS to arm PL and back-spacing pawl BP. The latter engages BFW and turns the feed shaft in a direction reverse to the normal. This takes place every time the back-spacing key is operated, the tape being pulled back letter by letter.

By either of the storage devices described it is possible for the rate of transmission, which is fixed by the number of revolutions of the distributor brushes, to vary from the rate of setting up either the letter pins or the punched holes in the tape. The perforator is usually placed close to the transmitter, and so long as the operator keeps a few letter-signals ahead, there is no risk of the tape being torn. It is customary with modern installations to interpose an automatic device which will stop the transmitter when the number of stored letter-signals on the tape has reached a minimum, usually 10 to 12 letters. The operator is thus relieved from any nervous strain due to anxiety from the transmitter catching up while few letters intervene between the perforating and transmitting points. To make the device completely independent of the operator, automatic starting should also be provided for. The transmitter must not either start or stop in the middle of a letter signal, since either the group of transmitter contacts would remain undisturbed in the position last set, thus sending the same letter repeatedly, or the group would be broken up, thereby mutilating the signal and a wrong letter would be printed at the receiver.

The solution of the problem of the completely automatic

"stop and start" fulfilling the necessary conditions was first accomplished by Murray and is illustrated by Fig. 22. Five transmitter levers TL are mounted on a pivot 4. The upper end of the levers are fitted with pins adapted to enter the holes presented to them by a perforated tape coming from the die block DB of a perforator placed close alongside the transmitter. The pins are forced into the perforations by springs S, and the transmitter levers control five contact-springs CS connected to the transmitting segments of a distributor. These springs normally rest on their upper or negative battery contacts, and when depressed make contact with a positive battery. A cadence current received once per revolution from the distributor operates magnet CM, the armature of which by means of rod R removes the right-hand arm of the bell-crank lever BCL through a slight angle in a counter-clockwise direction. A roller R working on the under surface of any of the transmitter levers which have moved forward, withdraws their pins from the tape, and at the same time the pawl FP engages the feed-wheel FW, moving the tape one letter space in the direction of the arrows. The control of the transmitter is effected by the arm SA pivoted on the frame at 1 and having its extreme left end so bent round that the tape passes over it on its way to the transmitter feed-race from the perforator die-block. As the stored signals diminish, the loop of tape shortens and finally engages the arm SA, pulling this down against spring S. The hooked stop lever SL is thus gradually lowered and will engage the hooked extension of the armature of the cadence magnet. This it can only do when the armature is in the attracted position, and thus all the transmitter levers are withdrawn from the tape and negative or non-operative current passes to line. When the tape accumulates again, SL will experience a pull tending to raise it, but it can only escape when the armature is again in the attracted position, so that the transmitter becomes free again at the right moment. Once the day's work is started, the operator has no concern as to the action of the transmitter but can concentrate him or herself on dispatching the traffic by the medium of the perforated tape.

The automatic stop-and-start device is not absolutely necessary, but its omission lowers the efficiency of a high-capacity circuit. Murray's invention in its original form provided only for manual operation of the stop and start, but this is not nearly so satisfactory as the subsequently-developed automatic arrangement. The essential feature of the invention is catching or releasing the armature of the transmitter magnet at the moment when it is attracted. Obviously this can be done electrically as well as mechanically, and several modifications have been devised for electrical operation. An entirely different plan from that evolved by Murray has been proposed, namely, to start the keyboard perforator working automatically so as to produce blank tape whenever the loop of tape gets used up. Unfortunately this device wastes tape and apparently interferes with the free manual operation of the keyboard perforator. Up to the present the Murray arrangement appears to be the most practical plan. Without some scheme of this kind the perforated tape has to be introduced into the transmitter afresh for each message, and transmission close up to the perforating point, with its great advantage of quick handling of traffic, is not possible.

## PART II.

Translation of the signals. General considerations. Various forms of translator. Overlap of printing and setting cycles. Electrical and mechanical setting means. Methods of effecting impression. Typewriter mechanisms. Page printing. Line feed. Letter feed. Page-up devices. Forms of blank for page printing. Principle of letter-counting mechanism.

Having dealt with the alphabet and its transmission over the line by the intervention of the composing and distributing apparatus, the next part of the subject requiring attention relates to the principles involved in the design of the mechanism required to translate the current permutations into printed characters at the receiving end of the line.

The signals in the line, being time signals, are transient in their effect on the receiving electromagnets, and, as the latter are set successively, it is necessary to arrange that the act of translation be suspended until the whole setting cycle is passed through. This condition will be met if the setting magnets are arranged to trip some trigger device, electrical or mechanical. In general, there are three cycles to be considered: (1) the setting cycle; (2) the printing cycle; and (3) the resetting cycle; and they occur in the order given.

The operations are perhaps most easily seen by reference to Fig. 23, in which magnets SM, to SM<sub>5</sub> release pawls P<sub>1</sub> to P<sub>5</sub> singly or in combination, in accordance with the letter-signal received. The five pawls hold five switch bars locked in the position shown in the drawing. Any pawl acted upon by a setting magnet releases its corresponding bar, which is then pulled upwards by a coiled spring at its upper end.

For any particular re-arrangement of the switch bars, a circuit will be completely closed for battery P B through one of a series of magnets KM controlling character-key levers. As the re-arrangement of the switch bars is not a simultaneous operation, means must be taken to prevent premature operation of the printing circuit, which would result in the wrong letter being printed.

A sixth line signal following the five setting-impulses actuates magnet PM, which pulls up a sixth switch bar and bridges a gap in the circuit of all the key-lever magnets. The sixth impulse can, of course, be sent locally by contacts on the distributor D. The sixth bar is provided with a non-return pawl NRP, which on its upward journey passes harmlessly by a horizontal bar RSB. When the magnet PM is de-energized, the pawl on the sixth bar engages the resetting bar RSB on its downward passage, meets the resetting pins RSP of any of the switch bars which may have been operated, and resets them in the normal position of the drawing, ready for the next letter signal. This translator represents no apparatus in actual existence, but it shows very clearly some features which appear in many modern translators, as will be clear from later descriptions.

Fig. 24 is a translator invented and discarded by Baudot during the early stages of the development of his printing telegraph, and merits description from the fact that it has been revived in the Siemens and Halske high-speed printer and has been shown to be capable of astonishing performances. The setting magnets are polarized relays, and when adjusted without bias the armatures will remain in what-

ever position they may be placed. This property enables the letter signal to be stored and, moreover, no special re-setting operation is necessary, as the next letter signal received effects this.

Running synchronously with, but independently of, the distributor contact-brush arm DCB is a second contact-brush arm CCB adapted to sweep over six concentric rings of contacts. The outer circular row has 32 segments, and the others 16, 8, 4, 2, and 1 respectively. The even-numbered segments are white, the odd numbers are coloured black, and the even-numbered segments of a row are connected together and to the right-hand or positive contacts of one of the setting relays P R. The sixth or inner circular segment is connected to a battery B, through the printing magnet P M, and to the relay armature of relay P R<sub>6</sub>.

The concentric rows of segments do not occupy the whole circular space, and the blank portion corresponds to the time during which the polarized relays are being set from the distributor D. The contact-brushes CCB connect the six concentric rows of segments together in pairs. These are arranged on a circular disc, and together with the revolving arm CCB form what Baudot termed a combiner, since the complex signal represented by the setting of the relay tongues is by this device translated into the single signal represented by the printing-hammer P H pressing the paper P against the type-wheel T W.

The type-wheel is mounted on the same shaft as CCB and rotates with this. On the same shaft is mounted a cam P F C, which acts on the feed lever F L to move the feed ratchet-wheel F R once per revolution. This wheel rotates a drawing roller, D R, and the paper is fed through one letter-space by these means. The type-wheel has characters around the rim equal in number to the segments of the outer ring of the combiner, and the printing circuit is closed for one of the radial positions of CCB in accordance with the setting of the five polarized relays. If, for example, the line signal is + - + - +, the printer circuit will be closed when CCB is on the radial position reckoned from the second inner circle outwards, "white, black, white, black, white."

The type character corresponding to this line signal will then be at the printing position and will be printed by the action of PM on the hammer P H. An ink roller, not shown, keeps the type-wheel inked.

Fig. 25 illustrates the principle of a translator, also invented by Baudot, and consists of five differentially-slotted bars P B. These are adapted to slide to the right, and for any given re-arrangement a complete slot will be formed, allowing one of 31 selector bars seen in the lower part of the diagram to drop.

In place of bars, Baudot showed that discs may be used, rocked about their common axis, the selector bars being then placed around radially as in the next figure.

Both these forms of mechanism have given rise to innumerable suggestions for translator mechanisms, a few of the most useful of which the author has selected for illustration.

In Fig. 27 the selected bar SB closes contact-spring CS, controlling magnets operating character-key levers of a typewriter.

Fig. 28 illustrates the disc arrangement of Fig. 26. Only one of the selector bars for a given setting of the

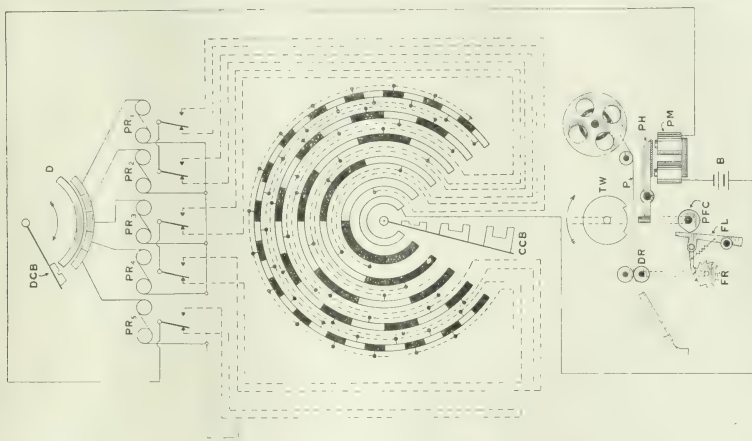


FIG. 24.—Early Bandol translator.

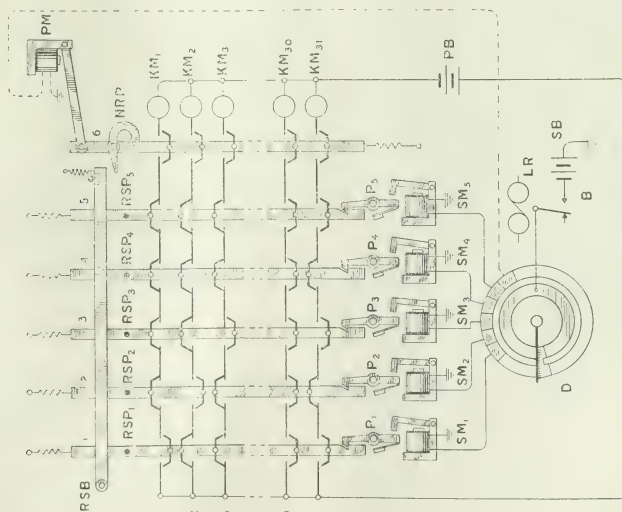


FIG. 23.—Translator for 5-unit code.

discs rotates on its pivot P and falls inwards into the aligned row of slots in the discs. A type-wheel TW is continuously rotated by a friction or slipping drive FD. The shaft carries at its upper end a stop-arm SA, and

the lever CKL into the path of a universal actuator bar. When the magnet M is actuated, which occurs immediately after the permutation bars are set, it withdraws a universal bar UB. This has two functions; first, it prevents pre-

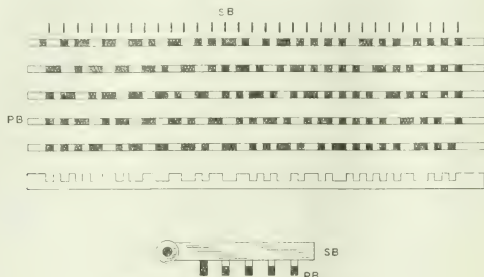


FIG. 25.—Permutation-bar translator (Baudot).

during rotation this meets the selector bar which has fallen forward, and the type-wheel is thus held stationary while printing is being effected. The discs, stop-arm,

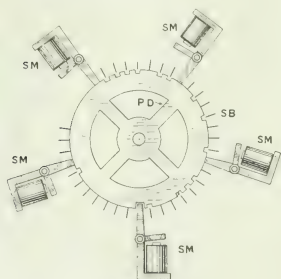


FIG. 26.—Permutation-disc translator (Baudot).

and selector bars form a differential stop-device for positioning a type-wheel, and are about the only satisfactory way to effect this. Invented originally by Steiger,

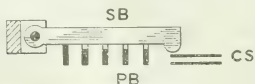


FIG. 27.—Method of applying permutation bars.

the principle has been introduced in the printing telegraph system adopted by the Western Union Company.

Fig. 29 is a typewriter translator designed by Murray. Here the selector bar trips a small hook H connected to

mature selection before the setting cycle is completed; and, second, after printing, the selector bar operated is pushed away from the permutation bars, allowing these to be set for the next letter. The actuator bar engages the hook H and pulls down the character lever, effecting printing as in the ordinary typewriter of commerce.

Fig. 30 represents a variation due to Caswell. Here the actuator bar fulfils the two functions. In the position shown the permutation bars can be set, since the selector

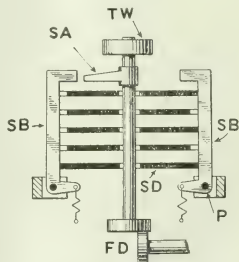


FIG. 28.—Steiger's permutation-disc translator.

bars all rest clear on the universal actuator bar fixed across the rocking frame RF. When the cam C moves round, it engages the small roller on the rocking frame and A B is pushed to the left; in doing this the slot cut in the selector bar allows it to drop so that it partakes of the movement of A B and rocks the bell-crank lever B C L, depressing the typewriter key. On the return motion of the rocking frame the actuator bar comes against the sloping surface of the slot in S B and lifts this out of the slot formed by the bars P B, releasing these for the next setting.

Fig. 31 is a construction proposed by Sacco and Giacomini; B is a barrel driven from a power shaft by a one-revolution clutch. Pins P are arranged around the barrel in the form of a helix. Rigidly fixed to the same shaft is a type-wheel, which thus revolves with the barrel. As before, the setting of the permutation bars determines the fall of one of 31 selector bars, which drops on to an actuator bar carried underneath them by a rocking frame

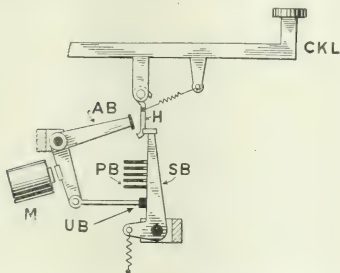


FIG. 29.—Murray's permutation-bar typewriter printer.

RF. As the corresponding pin comes round, it meets the selector bar which, in its lowered position, is in the path of the pin and the bar is depressed, rocking the actuator frame and bringing the paper tape against the type-wheel to print.

Fraser of the Eastern Telegraph Company has proposed a somewhat similar arrangement.

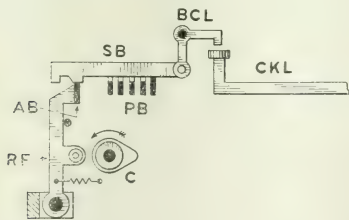


FIG. 30.—Caswell's permutation-bar typewriter printer.

The next translator, Fig. 32, is a variation of Fig. 28 using bars instead of discs, and is due to Eglin of the French Administration. The type-wheel is constrained to turn by a friction drive, but is held from rotation by a stop-pin SP<sub>1</sub>. When a selector bar drops, the actuator bar lowers the stop-pin and the type-wheel starts rotating. Each selector bar controls a second stop-pin, and pushes this up so as to stop the type-wheel when the stop-arm comes round. The second stop-pins, one for each selector bar, are arranged in a circular row of holes in the base-

plate P, and so form a differential stop for the type-wheel. An auxiliary lever PL is pivoted on the stop-arm, and this is raised by the action of the selector-bar stop-pin, lowering

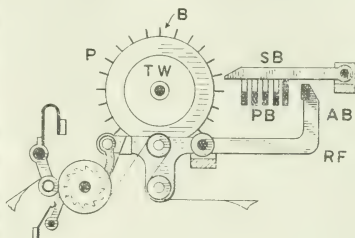


FIG. 31.—Sacco and Giacomini's permutation-bar type-wheel printer.

a sleeve which is loose on the type-wheel shaft. This sleeve closes two contact springs CS, and the circuit of battery PB is completed through the printing magnet PM,

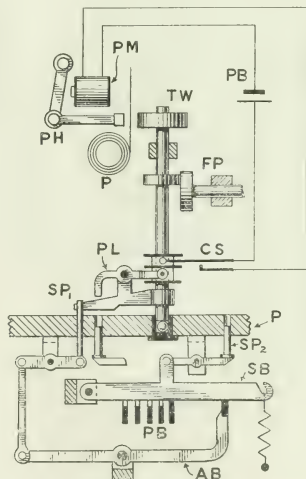


FIG. 32.—Eglin's permutation-bar type-wheel printer.

the armature of which drives the printing hammer PH forward and presses the paper against the type-wheel. The number of translators which can be designed is very great, as there are so many possible ways of solving the

problem; the few examples illustrated, however, are mostly in practical use.

In a translator using permutation bars it has been pointed out that a universal bar is necessary not only to prevent premature selection of the wrong selector bar, but also to lift this clear of the permutation bars ready for another setting. The latter function is not required if the notches are sloped on one side as in Fig. 33. The sloping surface will lift any selector bar up if the displaced permutation bar is drawn to the right, its normal position. The universal bar may be entirely dispensed with by arranging for these notches with a method for simultaneously setting the desired permutation bars as in the schemes shown in Figs. 42 and 43.

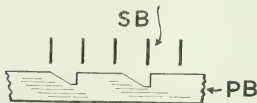


FIG. 33.—Permutation bar with sloping notches to effect return of selector bars to normal.

Fig. 34 illustrates a construction due to the Union Switch and Signal Company.

Here the five setting magnets release T-shaped latches L, which drop into notches formed on the ends of the bars PB. The latches L and their releasing pawls RP are pivoted on a rocking frame, and after the setting cycle is completed, a cam C on the power shaft oscillates the frame RF counter-clockwise. The latches which have been released and which engage the permutation bars set these as desired. After printing, cam C returns all the

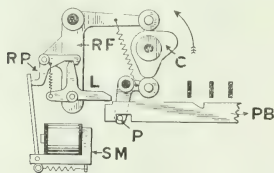


FIG. 34.—Union Switch and Signal Co.'s method of simultaneous shift of permutation bars.

bars to their normal positions by means of a pin P on a bell-crank lever also controlled by the cam.

In order that the speed of some of the operation cycles may be kept as low as possible without loss of line time, it is necessary to arrange that the setting and printing cycles overlap.

Fig. 35 shows the overlap designed by Murray for his first multiplex printer still in use between London and Manchester. In this after the permutation bars have been set and the selector bar has thrown the hook H R of the selected key lever in the path of the actuator bar A B, S B can return to normal and the setting process for the next letter be commenced before the printing process is completed. This is secured by the pawl P,

which locks the rod H R in the striker path and does not release it until A B has operated the selected key. The selector bar has merely to trip pawl P and is then free. The release of H R is secured by a projection on the pawl P striking a comb C, when H R is retracted to normal by the coil spring. In the Murray automatic printer overlap is secured by the actuator bar A B engaging the hook of H R. In Fig. 36 the selector bar is dropped on to the

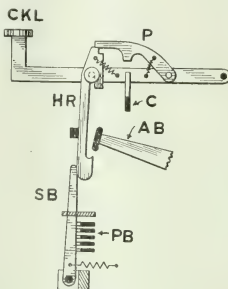


FIG. 35.—Mechanical arrangement of Murray's printer to allow overlap of printing and setting cycles.

actuator bar, and when the latter is rocked by the cam C it lifts S B out of the slots in the permutation bars and releases these for the next setting. This is a design of the late John Burry.

Fig. 37 illustrates theoretically a mechanical type-wheel translator due to Baudot which in modified form is in use to this day. Five discs D<sub>1</sub> to D<sub>5</sub> and a type-wheel T W are so connected that they all revolve together at the same

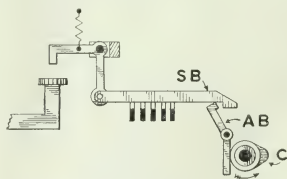


FIG. 36.—Method of securing overlap in Burry's type-bar printer.

speed and phase. If we cut five notches in the edges of the discs, then at any particular instant these will all occupy the position shown in the drawing. Pivoted to a frame not shown are six bell-crank levers B C L. These carry rollers on their lower arms adapted to engage the edges of the discs, and their upper arms are provided with pins which fit in open-end slots in a spring-controlled bar B. When the notches come uppermost, the levers all move to the position shown, through the action of the

spring S on bar B. Immediately after they are all smartly rejected from the notches and their simultaneous movement is transmitted through the bar B to the sixth bell-crank lever which controls a printing lever P L, printing being effected mechanically in any well-known way.

the attainment of speeds much beyond these figures. The electrical combiner of Baudot is worked at speeds three to four times that possible with the mechanical arrangement just described.

It has been shown that means have to be provided for

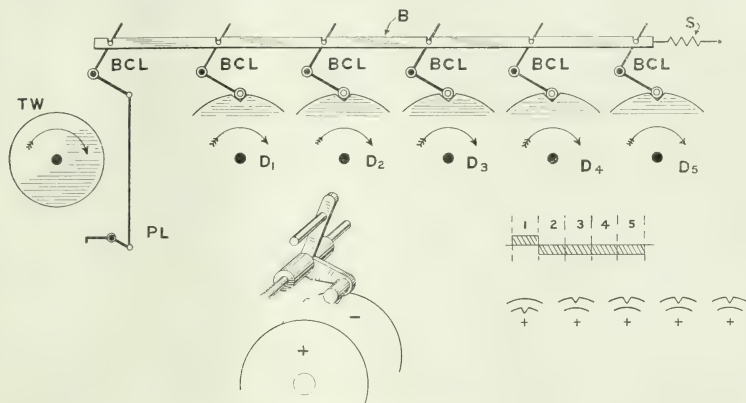


FIG. 37. —Mechanical translator of Baudot.

As described, the apparatus would only print one letter, but by using five pairs of discs and arranging for the bell cranks to be shifted by electromagnets so that the rollers rest on one or other of each pair as shown in the inset

storing the transient signals from the distributor. This may be done electrically or mechanically in a variety of ways.

Diagram A, Fig. 38, is a polarized relay with its

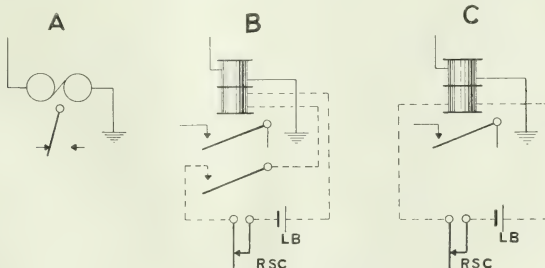


FIG. 38. —Electrical methods of storing transient signals.

diagram, 31 different letters may be printed. The small diagram to the right shows how the discs would be notched to translate the letter signal + — — —. This translator is capable of working up to from 40 to 45 words per minute, but theoretical considerations set a limit to

armature so adjusted as to remain on whichever of the two contacts it is placed. Diagram B is a non-polarized relay having a setting and a locking winding. When energized, one of its armatures closes a circuit through one coil for the lock battery LB, and the relay is held in

the energized position until the lock circuit is broken down by the resetting contact RSC being opened. Diagram C is a similar 2-winding relay, adjusted for "marginal operation." The local battery is normally joined in

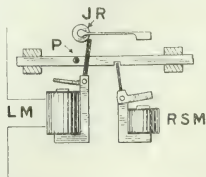


FIG. 39.—Electromechanical arrangement of storing transient signals.

series with one winding of the relay, but the air-gap and strength of current are such that the relay is inoperative. When the transient line current passes through the line coil, the armature is attracted and the local current can

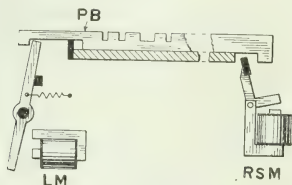


FIG. 40.—Electromechanical setting and resetting method for permutation bars (Murray).

now hold it. Resetting is accomplished by breaking down the local circuit. So arranged the relay is polarized and the line current must pass in such a direction that its current is added in its effect to that of the local current.

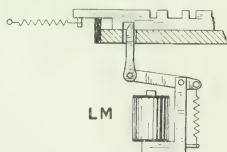


FIG. 41.—Electrical trigger as setting means for permutation bars (Murray).

Fig. 39 illustrates a mechanical method of storing the movement of an electromagnet. The armature of magnet LM carries an appendix adapted to come up against a pin P and move the slide bar shown to the left. The armature is then locked in the attracted position by a jockey roller JR pivoted on a flexible spring. Magnet and

bar are reset by magnet RSM. Fig. 40 is an arrangement due to Murray. Permutation bars PB rest in grooves and will remain wherever they are placed if moved by the line magnet LM. A resetting magnet RSM provided with a universal bar resets to the normal position.

In the next figure the permutation bars are moved by spiral springs, being released by an electromagnetic trigger. This also is due to Murray.

Permutation bars may be shifted by means of a per-

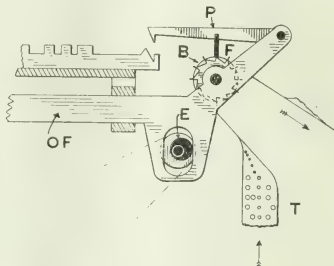


FIG. 42.—Mechanical method of setting permutation bars under the control of a perforated tape (Caswell).

forated tape. This is a common method in type-setting devices, but it has also found considerable application in telegraphy. Translators controlled by a perforated tape have been devised by Murray, Creed, Fraser, and Caswell. Both the Murray and the Creed apparatus have found extensive application.

Fig. 42 represents Caswell's translator. The tape T passes round a barrel B and under feelers F mounted on

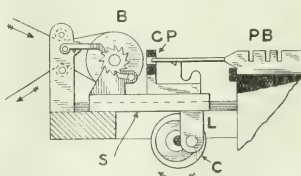


FIG. 43.—Perforated-tape control of permutation bars (Murray).

five or more pawls P. If there are no holes in the tape the pawls occupy the position shown, but wherever holes occur the corresponding pawls drop, and hooks at the ends fall into notches in the permutation bars. The barrel and pawls are supported in an oscillating frame OF which is reciprocated by means of an eccentric E fixed on a power shaft. On the return motion of the frame, a pawl, not shown, engages with a ratchet wheel on the tape barrel and feeds the tape round to the next letter.

A construction due to Murray is given in the next figure.

The tape barrel B is mounted on a shuttle S, reciprocated by a power-driven cam C acting on a pin in a lug L solid with the shuttle. The ends of the permutation bars are provided with small circular rods supported by a guide-plate G P on the shuttle. As the shuttle is moved towards the bars, these can pass into the barrel, or not, according as punched holes occur in the tape. Unpunched tape

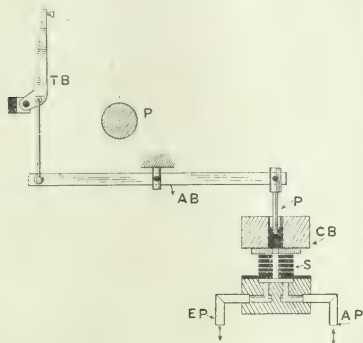


FIG. 44.—Compressed-air control of type-bars (Creed).

pushes one or more of the rods and moves the corresponding bar or bars to the right by reason of the shuttle motion.

In Murray's instrument the movement of a bar is determined by unpunched tape, while in the Caswell apparatus the movement of a bar depends on the punched portion of the tape.

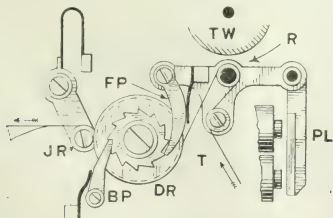


FIG. 45.—Simple form of impression and paper feed for tape telegraphic printer.

Fig. 44 illustrates in diagrammatic form the beautiful printer due to Creed. With this printer each type-bar has its own actuator bar AB controlled by a small piston mounted in a cylinder block CB. The desired piston is selected through a series of slides S, which for a given re-arrangement present a clear passage for the air port AP which is connected to a source of supply of

compressed air. The air entering the cylinder through the permutation slides moves the piston outwards and brings the type-bar TB down on the platen P through the linkage shown. Inlet and exhaust ports, not shown, are opened at proper times during the complete cycle of operations. Actually Creed uses 10 slide-bars, positioned by a Wheatstone tape, but his printer can be arranged for the 5-unit code, as shown in the drawing. The align-

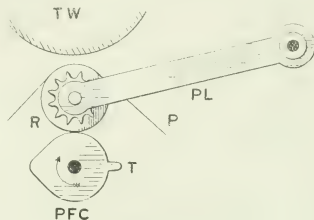


FIG. 46.—"Flying print" of David Hughes.

ment of holes in a series of slides was first proposed by Highton in 1848.

Before leaving the subject of translators, it is advisable to glance briefly at a few methods of effecting impression from a rotating type-wheel on a paper tape.

Fig. 45 is the oldest method in which an electromagnet acts on a printing lever PL to force the tape T resting on a roller R against the type-wheel TW. The release of the

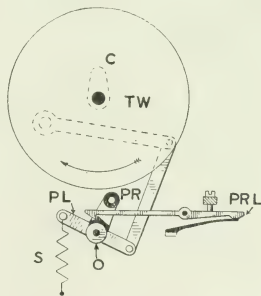


FIG. 47.—Principle of "rolling print."

printing lever effects the paper feed in the following manner:—

The tape passes round a drawing roller DR against which it is tightly held by a spring jockey-roller JR. On the release of the printing lever, the feed pawl FP, which had been moved to a tooth above the one on which it is seen to be resting in the drawing, rotates the drawing roller to the position shown, feeding the paper through one letter space.



Fig. 49 will enable a clear grasp to be obtained of the various conditions to be met, although it is only a diagram and not a drawing of any particular construction. The paper, as is known, is usually wound round a rubber-faced roller or platen P supported in two bearings by means of a shaft S carried by a rectangular frame F. F is provided with four

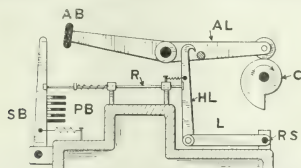


FIG. 50.—Power control of operations on a type printer determined by setting of permutation bars (Murray).



FIG. 51.—Power-control operations set by permutation bars.

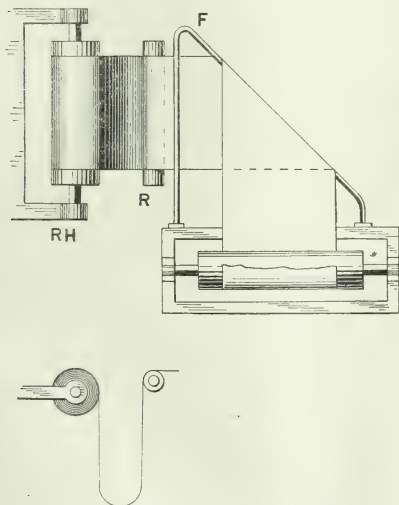


FIG. 52.—Form of paper blank and carriage to give freedom of movement to printer platen.

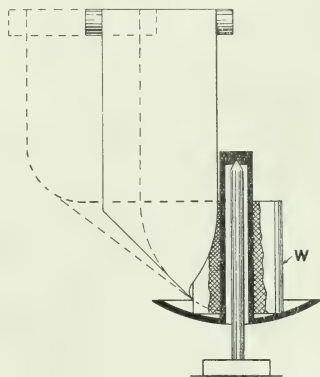


FIG. 53.—Web holder and platen arrangement for page-printing telegraph (Western Electric Co.).

grooved rollers R, which run on two slide-rails SR fixed to the body of the apparatus. The frame F is normally at the extreme right-hand side of the apparatus and is moved to the left by the following mechanism. Anchored to the main frame at any suitable point is a coiled spring S, which by means of a flexible steel strap is connected to the platen carriage over a series of guide rollers. The other end of

when operated depresses a universal bar UB and allows the pin wheel PW to escape one tooth only, thus allowing the carriage to move to the left a definite distance each time a character key strikes the universal bar. The escapement details are shown in the right-hand bottom corner on a larger scale. The pin P of the escapement wheel is normally caught by a flat leaf spring LS riveted to the side

of the bar E. When this bar is lowered by the action of the universal bar U B, the pin escapes over the top of the spring, but is still held by E. On the return motion, P slides between the spring and E until a rectangular hole cut in E comes opposite to the pin. When this happens P escapes and the next pin coming round is caught by the spring L S. If the pin wheel were revolved in the opposite direction it would be perfectly free, since each pin would deflect the spring as it came round and slip over the top

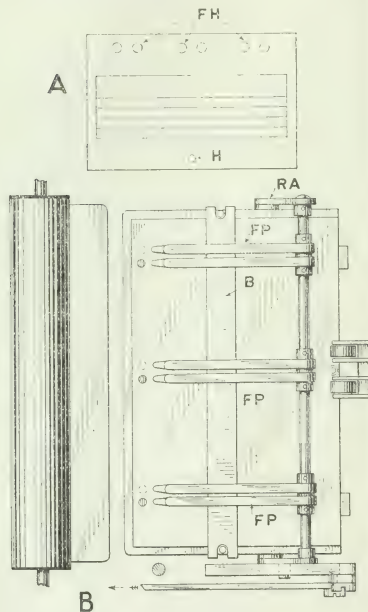


FIG. 54.—Printing telegraph paper-feed from pile of cut blanks (Murray).

edge. This allows of the return of the carriage to commence a fresh line. This carriage-return is accomplished by tripping a clutch, connecting a power shaft to the drum D, and pulling the carriage back to the right.

The line feed is accomplished automatically by a feed pawl FP coming in contact, when at the extreme end of a line of print, with a cam FC fixed to the main frame. A ratchet wheel fixed to the platen shaft is thus fed up one tooth, moving the platen correspondingly to give the line feed.

The various mechanical operations incidental to a page-printing telegraph can all be carried out by special signals

sent over the line, and Fig. 50 is drawn to illustrate this. Five permutation bars P B effect the selection of a selector bar which does not, in this instance, control the printing of a character. It pushes instead, by means of a spring-retracted rod R, a hooked lever H L on to a pin fixed on the actuator lever A L. As the power shaft makes a revolution the cam C causes A L to oscillate and the hooked lever is raised. By means of the link L this motion is communicated to a rock shaft R S, which can be provided with attachments to trip a clutch, feed a ratchet wheel, or perform any similar operation. This arrangement forms part of one form of the Murray multiplex printer.

Another method is shown in the following figure. Here the selector bar rotates round a pivot on a link L, and its right-hand end comes into the path of a cam C pivoted on the main frame and driven by the motor M. When the two engage, the selector bar and link L are pushed to the left in the direction of the arrow, and this motion may

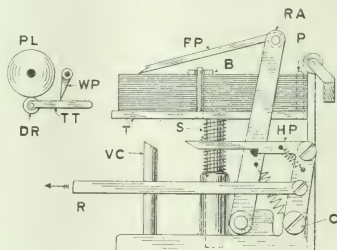


FIG. 55.—Paper feed from pile of cut blanks (Murray).

be used to actuate a character key or operate any other mechanism.

Quite an important consideration with a page-printing telegraph is the form of the paper blank. Usually a continuous roll or web is employed perforated at intervals apart equal to the depth of the form in use by the Administration. The usual printed heading may be provided, or this can be very successfully applied afterwards by a small printing-press. The latest arrangement is to use the existing forms of the Administration and feed these into the printer in much the same way as is done with the automatic feed used with printing presses. If the web form of blank is to be used, special methods have to be devised in order that the freedom of movement of the platen carriage may not be interfered with.

Fig. 52 shows a satisfactory arrangement for effecting this. The paper is led from a roll holder R H, and after hanging loosely passes over a roller R, after which it is bent at right angles over a wire frame F fixed on the carriage passing to the platen as shown.

Fig. 53 is an arrangement employed by the Western Union Company. The web rests in a circular holder hung on a pivot so that the centre of gravity of the whole rests below the point of support. The roll is at all times in stable equilibrium due to this arrangement, and the paper

carriage is capable of transverse movement without any tendency of the paper to twist or warp.

Figs. 54 and 55 illustrate the arrangement for feeding cut blanks from a pile into the printer; this arrangement is due to Murray. Reciprocating rollers or suckers are employed to feed the paper in sheet form to printing presses, but the occasional mis-feeding or mutilation is of little consequence, since the machine is printing the same thing repeatedly. In the case of a printing telegraph such an event cannot be permitted, as each blank has different matter printed on it, and any accident of the kind would necessitate the message being re-transmitted, thus causing delay. The feed device must be very positive and the

are mounted on a shaft running between two rocking arms RA pivoted on the base. According to the position of the set of feed holes FH, one set of feed pawls will engage the topmost blank and separate it from the pile when they are moved forward to feed.

The feed is accomplished in the following manner, best seen from Fig. 55. A rod R, at the moment when the blank previously in the machine is rejected by mechanism yet to be explained, is moved forward in the direction of the arrow. R is connected to a crank C, which has a horizontal pawl HP engaging the rocking arm through a pallet shown in black. As R moves forward the feed pawls separate the topmost blank and push it on to the

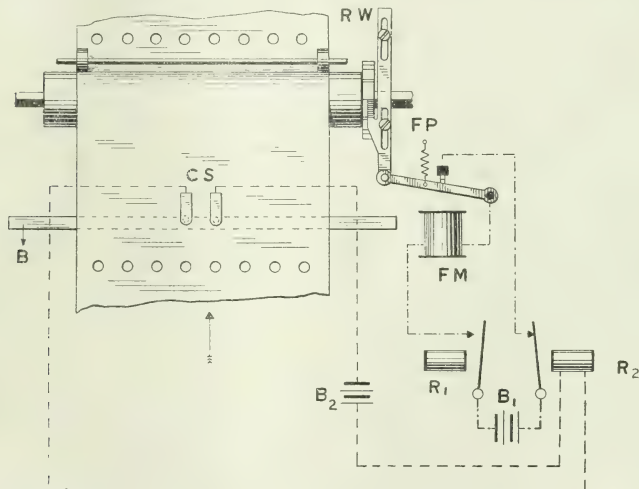


FIG. 56.—Page-up device for page-printing telegraph.

separation of the top blank from the pile must be a matter of certainty. Murray takes the standard form of blank in use and punches four holes in it (Diagram A, Fig. 54). The hole marked H is in the same position in all the blanks and is provided to enable the blanks to be threaded on a pin P (Fig. 55) on the table T. The other three holes in the top of the blank are staggered as shown. The blanks are assembled in pairs and the sets of holes are displaced alternately as shown in Diagram A. They are then placed on a table T fixed on a pillar which slides in a socket on the base of the apparatus. A spiral spring S is inserted between the table and the socket, and this ensures that the top of the pile of blanks always remains at the same level as the pile diminishes. A bar B rests on the top of the blanks and keeps these flat. Three pairs of feeding pawls

table T T, where it is retained against return by the wedge pawl WP. Its foremost edge is caught between the platen PL and the drawing roller, and it is drawn in to the printing position as explained later. The pawls FP are released by the action of a vertical cam surface VC, which encounters HP and lifts this free from engagement with the pallet on the rocking arm RA and the latter returns to normal, carrying with it the pawls, the spiral retracting-spring securing this. When the rod R returns to normal, HP engages RA again ready for the next operation.

Another automatic feature of the modern page printer is the paging-up of the telegram form at the completion of the message.

Fig. 56 represents an automatic page-up somewhat on the lines of the arrangement used in the Rowland Printer. The

blank is in the form of a web, perforated at intervals by a horizontal row of holes. Telegraph messages are variable in length and the amount of page-up required will usually be different for successive messages. The blank in Fig. 56 is placed round the usual platen adapted to be rotated by a ratchet and pawl controlled by a self-interrupting feed-magnet F.M. When the message is finished, the distant transmitting operator sends the page-up line signal and relay R, is operated, closing the circuit from battery B through the feed-magnet. The armature of this vibrates, rotating the platen through the feed pawl F P and ratchet wheel R.W. Two contact springs C.S. press against a metal bar B with the paper intervening, and when the row of perforations reach the bar these springs are connected by making contact with the bar through the holes in the paper. When this occurs, a circuit is closed for battery B, through relay R, and the latter acts to cut off current from battery B, to the feed-magnet, the feed then ceasing. The normal line feed is accomplished by means not shown.

Murray accomplishes the same result in a purely mechanical manner, using the arrangement of Fig. 57.

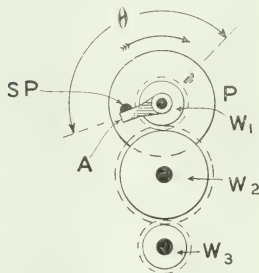


FIG. 57.—Page-up device for printing telegraph (Murray).

P is the platen carrying a stop-pin SP; loose on the platen shaft is a gear-wheel  $W_1$ , which is coupled by an idle wheel  $W_2$  to another gear-wheel  $W_3$ . The whole train is normally at rest,  $W_3$  being locked, while  $W_1$  is free on the platen shaft and does not interfere with the free movement of the platen. Rigidly connected to  $W_1$  is a driver A, and when the page-up signal is received,  $W_3$  is released and makes one revolution. The gear ratios are such that  $W_1$ , and with it the driver, also make one revolution. If the platen has been stepped round to give line feed, the stop-pin SP will have moved through some angle  $\theta$  which will vary for each message, consequently the driver will only turn the platen through an angle  $360 - \theta$ , thereby rejecting the blank and drawing forward the next one to the printing point. The diameter of the platen or the gear ratio must be so chosen that one revolution of  $W_3$  will feed a distance equal to the printing point on one blank to the printing point on the next, and the amount of page-up will then always correspond to the length of blank represented by  $360 - \theta$ . The drawing is only diagrammatic.

The last point to be considered is the counting mechanism employed to indicate to the transmitting operator when to send the line signal to feed up for a fresh line.

In Fig. 58 the universal bar UB moved by the character keys carries a pawl P adapted to rotate a ratchet wheel step by step. Solid with R.W. so as to rotate with it is a disc D provided with a projection L and a single tooth T. This combination rotates in the direction of the arrow

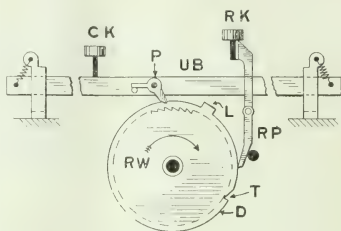


FIG. 58.—Letter-counting mechanism for transmitter of page-printing telegraph.

until it has made a complete revolution, which it will do when the number of letters equal to a full line have been transmitted. At this point, projecting L will come under the universal bar, locking this and therefore the keyboard. Release is accomplished by depressing the release key, which also sends the line feed-signal to line, and releases the keyboard, its pawl R.P. entering the single tooth T and carrying D and R.W. round so that L is now clear of U.B.

### PART III.

One-channel low-speed printing telegraphs—Buckingham, McCaskey, Pierart. Chain relay system of Morkrum, Harrison, Kirk Himrod.

A number of printing telegraphs operated manually with distributors worked step by step from the signals have been proposed from time to time by McCaskey, Kirk Himrod and others, but the single-channel low-speed printer using the Baudot alphabet has not been applied until comparatively recent times.

The extensive and ever-increasing use all over the world of the high-capacity printing telegraph will help the development of its smaller brother; and since the latter, if suitably designed, can be worked by perforated tape and also be made to furnish a punched slip for retransmission on the trunk-line systems, its adoption on circuits carrying comparatively little traffic may be confidently looked forward to.

C. L. Buckingham was early in the field with the system depicted in Fig. 59. The distributor D is driven step by step by the electromagnetic escapement E controlled by the line signals. The stepping impulses, which are alternately positive and negative, would invariably actuate the setting magnets, if it were not for a special arrangement

designed to prevent this. The line relay L R alternately closes the circuit of battery B through the escapement magnets M,  $M_1$ . In series with L R is a slow-acting relay S A R, which is unaffected by the stepping impulses but will act if any of these are prolonged. When energized, S A R closes the circuit of battery L B through the distributor D to the setting magnets S M. Selection is thus accomplished accordingly as the first five impulses of a letter signal are prolonged or not. The sixth impulse effects printing.

The transmitter T consists of a metal drum continuously rotated by a motor not shown. Two earthed transmitter

worthy as showing that a step-by-step distributor can be worked at speeds ranging from 80 to 100 words per minute.

Fig. 60 represents an arrangement on the lines of that proposed by McCaskey. The distributor contact-brush arm C B A at the transmitting end is driven by a friction or other form of slipping drive, but is normally held against rotation by a stop-pin on the armature of the starting magnet S M. Depression of one of the character keys acts, by means of the differentially toothed bar pivoted to the key lever, on a series of five rocking frames controlling transmitter contacts. The transmitter contacts are con-

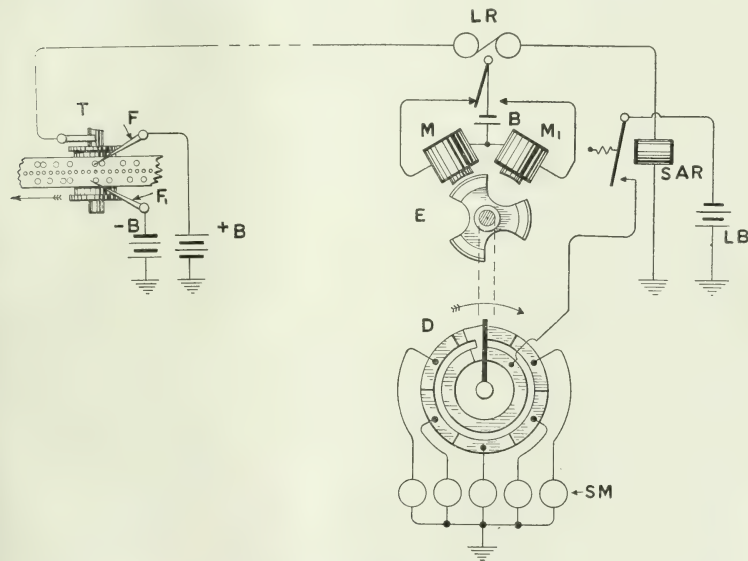


FIG. 59.—Step-by-step printing telegraph (Buckingham).

batteries are connected to fingers F and  $F_1$ , and these make contact with the drum through holes in a perforated tape. The impulses are long or short accordingly as the holes in the tape each side of the feed holes are opposite to each other or displaced. The finger  $F_1$  is slightly longer than F, so that it enters the lower hole in the tape after F has left the hole vertically above it. All letters have the same number of impulses, but different time values, depending upon the number of magnets S M to be set. The Buckingham system underwent several departures from the simple system shown in the diagram, and has long since disappeared from practical work, but it is note-

connected to the ring of five contacts on the distributor D, and the positive or negative signalling battery is joined to the distributor contacts, corresponding to the current permutation representing the letter signal assigned to the character key.

The operation of a character key acts in addition on a universal bar, and completes a starting circuit through the starting circuit S M, condenser C, and battery S B. The momentary rush of current through the condenser effects the release of the contact-brush arm C B A as the armature of the starting magnet is attracted, drawing its stop-pin clear. This current is only transient, and when C B A

comes to the normal or starting position, it encounters the stop-pin and is again held. The condenser in the starting circuit is equivalent to a mechanical trigger, and the key lever CKL may be held down indefinitely, but the brush arm will only make one revolution. When the key CKL is released, the condenser discharges through the resistance R. This starting circuit is due to Siemens and Halske.

The current permutation passes to line and through two polarized relays  $R_1$  and  $R_2$  to earth.  $R_2$  closes the circuit of a local battery LB through a driving magnet DM, for both + and - signalling impulses. DM controls by a double acting ratchet DAR and the ratchet wheel RW the

The receiving distributor is shown with a second group of receiving segments. These are simply connected in parallel with the first group.

In the normal position of the transmitting distributor a circuit is closed through a magnet ULM. This attracts the locking frame LF and any key can be operated. When a key is depressed, the distributor brush leaves the lock contacts LC and the frame drops back, locking the depressed key in the operative position until the distributor has made an entire revolution.

The next figure illustrates a suggestion made by Pierart of the Belgian Administration. Escapement mechanisms are used at both ends of the line, and the transmitter key-

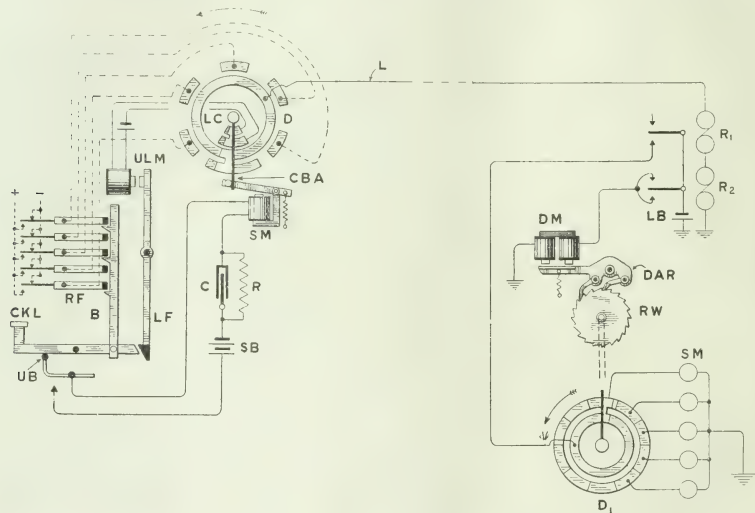


FIG. 60.—Step-by-step printing telegraph (McCaskey).

contact-brush arm of the receiving distributor  $D_1$ . When an impulse of either sign is received, DM moves the ratchet wheel through one tooth space, and on the cessation of the impulse the retraction of the armature feeds the wheel another tooth space, so that for five impulses the wheel will move through 10 teeth corresponding to half a revolution. A necessary consequence of this method is that zero impulses shall intervene between each signal element of a letter.

Selection of any or all of the setting magnets depends upon the sign of the signal impulse. Positive impulses cause relay  $R_1$  to close the circuit of LB through its + contact, through the distributor contacts, the setting magnet, and earth.

The "trigger" consists of a slow-acting relay SAR of low resistance, through which the negative earthed signalling battery is taken. When a key is operated, a circuit is closed from the negative battery through SAR, UB, the armature of SAR, the back contact of the same, the starting segment S of the distributor, and the line relay to line. The distributor makes one step owing to the energization of the escapement magnet, and the brush arm now breaks the line circuit. As a result the line relay LR de-energizes, and the escapement makes another step, the brush arm moving on to segment No. 1. This process will now continue throughout the whole cycle, but not beyond this, as SAR has in the meantime operated and the starting segment is dis-

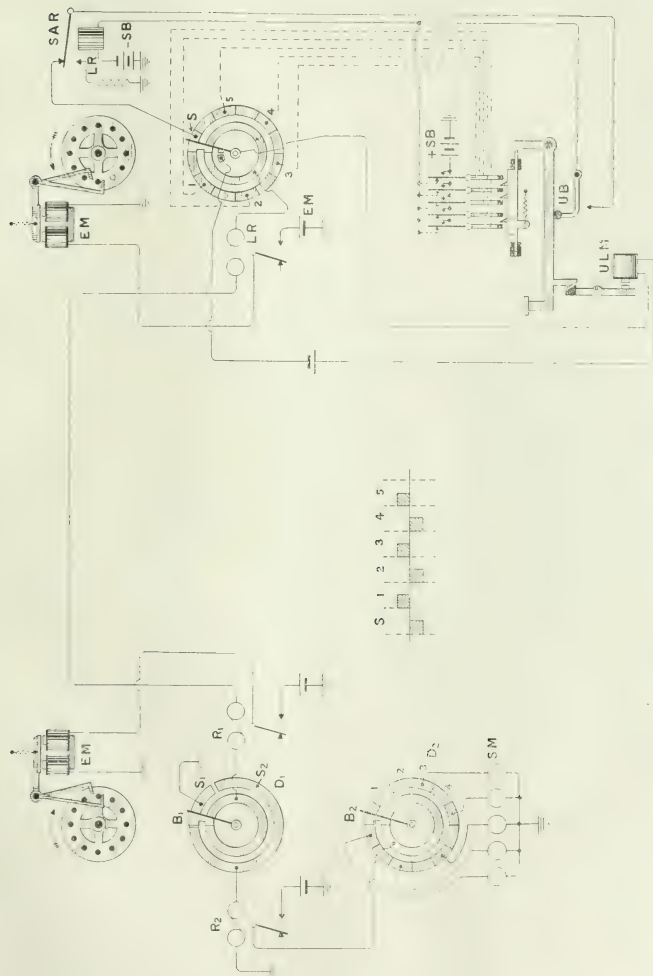


FIG. 61.—Step-by-step printing telegraph (Pierart).

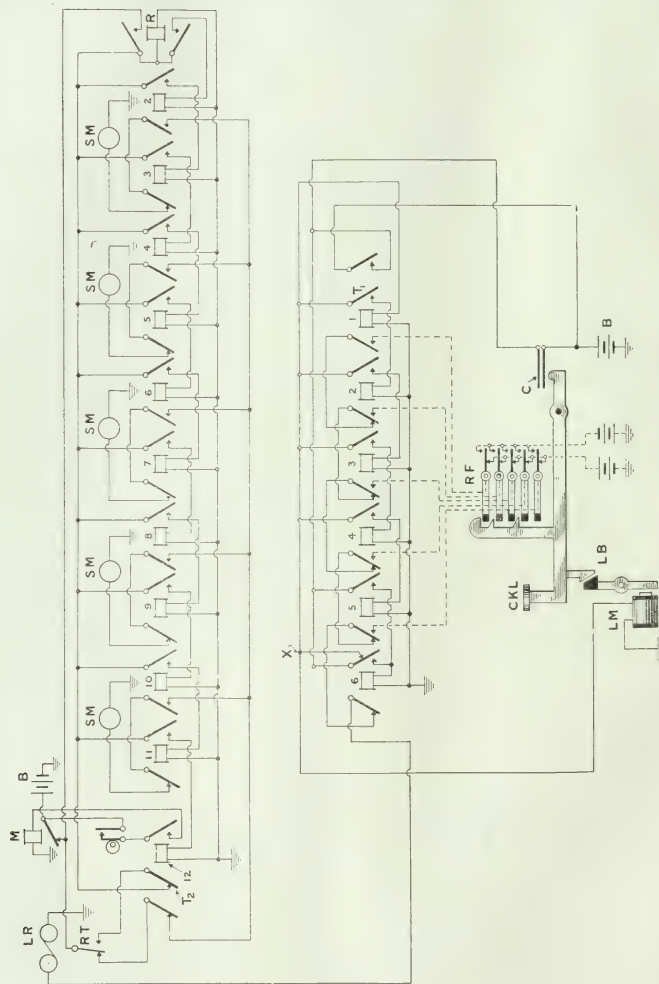


FIG. 62.—Chain relay step-by-step printing telegraph (Morkum).

connected. Thus the transmitter key must be released before another signal can be sent, SAR being locked through the leak resistance L. At the receiving end, the escapement controls two distributors D<sub>1</sub> and D<sub>2</sub>. In the position shown, the starting impulse from the transmitting end passes through relay R<sub>1</sub> to earth. The escapement magnet is actuated and the distributor brushes move through one segment. When the line impulse ceases, the retraction of the escapement EM moves brush B<sub>1</sub> to sector S<sub>2</sub>, and brush B<sub>2</sub> to segment 2 of D<sub>2</sub>.

Relays R<sub>1</sub> and R<sub>2</sub> are now in series with one another, and any subsequent impulses will step the brushes round, selecting the setting magnets as the impulses are positive or negative. The inset diagram shows the starting impulse S and the five signalling impulses corresponding to the Baudot letter T. Zero units still have to be used and the apparatus is thus what our American friends would call a "short line" printer.

By using a relay chain, step-by-step mechanisms can be dispensed with at both ends of the line. The next figure represents an early chain relay method due to the Morkrum Company. The operation is as follows:—

When the key is depressed it is locked mechanically by the lock bar, sets up the required current permutation by means of the five rocking frames, and closes a contact C for a battery B to the point X where the current divides, part going through the lock magnet LM and part through relay 1. This pulls up and closes a circuit from T through relay 2, and this goes on throughout the whole chain. When relay 6 is pulled up, the battery is removed from the point X by the right-hand armature of relay 6 disconnecting there, and the battery is now diverted through the coil of relay 6 to earth, locking this and preventing a repetition of the cycle until the character key has been released. The line circuit may be traced from the left-hand armatures of relays 6, 5, 4, 3, 2, and 1, and as these pull up in the order 1, 2, 3, 4, and 5, the current permutations are sent to line.

At the receiving end the starting and signalling impulses pass through a polarized line relay LR. The starting impulse moves RT over to the right-hand contact, allowing current from B to flow through relay R. As this pulls down, it starts the chain in operation from right to left. When relay 12 is energized, the right-hand contact of LR is disconnected by T<sub>2</sub> and all relays return to normal.

The setting magnets are selected by RT of the line relay being on its left-hand contact when the left-hand armatures of relays 2, 4, 6, 8, and 10 are pulled up. If RT is on its right-hand contact during any part of the chain, the corresponding setting magnet is inoperative.

The arrangement of the next figure, the Harrison printing telegraph, due to the author, removes the necessity for the zero unit in step-by-step printing systems using the 5-unit code.

The transmitter is arranged on the same lines as those previously described, and a starting impulse and trigger circuit is provided. Negative current normally passes from the battery TB through the armature SA of the starting magnet SM. This current will not operate the distant distributor, which remains at rest until the line current is reversed. When a signal permutation is set up at the transmitter SA is attracted and locked by current from the positive transmitter battery passing through one

winding of SM where it divides, part going through conductor 21 and distributor A to line, the remainder going through distributor B to the leak relay LR. This relay closes the circuit from battery B<sub>2</sub> through the escapement magnet, and both the distributors A and B move through 1/24th of their circular path. The circuit of LR is now broken at distributor B and this releases, breaking the circuit of the escapement magnet EM, when both distributors move through another 1/24th of a revolution. It is to be noted that current has been on the line the whole time, the disconnection necessary for stepping round the distributors being produced in a local circuit. What has been said for the starting impulse applies to the remaining five signal impulses, and no zero currents occur in the line, while if any pauses occur in transmission, protective negative line current flows all the time.

At the receiving end the polarized line relay controls two non-polarized relays NPR<sub>1</sub> and NPR<sub>2</sub>. During the time that no transmission is taking place and negative line current is flowing, NPR<sub>1</sub> is operated, but it does not start distributors C and D as the circuit of the escapement magnet is broken at the point X. When the positive starting impulse arrives, NPR<sub>1</sub> is operated and its second armature A<sub>2</sub> closes the circuit of battery LB<sub>2</sub> to distributor C, conductor 22, and the escapement magnet to earth. Distributors C and D move through 2/24ths of the circle in two steps, as explained in connection with A and B. After the starting impulse, the setting cycle commences and the escapement is worked locally by either of the two local relays and battery LB<sub>2</sub> through distributor D.

Provided the ratchet mechanisms have about the same period, the one will drive the other perfectly, and any change in current from positive to negative in the line will act to control them. Should they get out of step, a pause of less than a second will automatically restore unison, since for any but the normal position a negative current to line will operate the escapement.

This printer can be operated by a standard 5-unit perforated tape, and can be arranged to furnish a similar tape if required.

Before leaving this part of the subject one other device requires mentioning. In single-channel printers since the setting cycle must precede the printing cycle, a pause is necessary between letters while the printing is effected. This leads to waste of line time and the keyboard has to be locked. The loss of line time is not serious, but the bound keyboard is a grave disadvantage. To reduce the lost line time to a minimum and to approximate to a free keyboard, the printing is effected as rapidly as possible, which involves heavy wear and tear. By employing two groups of setting magnets, one group being set while the other is effecting printing, the printing and setting cycles completely overlap and no waste of line time occurs, while ample time can be allowed for printing and the keyboard is free. Signal storage between the keyboard and the transmitter is also of advantage.

Kirk Himrod was the first inventor to apply this principle to single-channel sets.

The Himrod arrangement is shown by Fig. 64. D is the distributor, and during its first half revolution it sets the right-hand group of the magnets SM, doing the same for the left-hand group in the next half revolution. RS is a rotary switch having a contact-brush arm CBA which

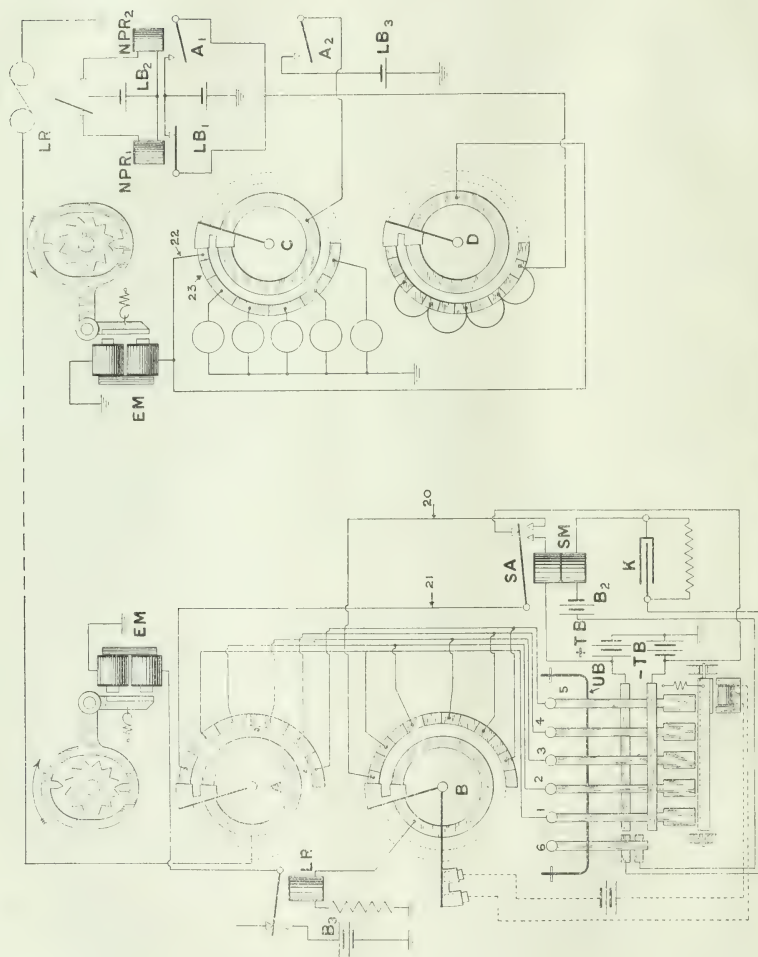


FIG. 63.—Step-by-step printing telegraph (Harrison).

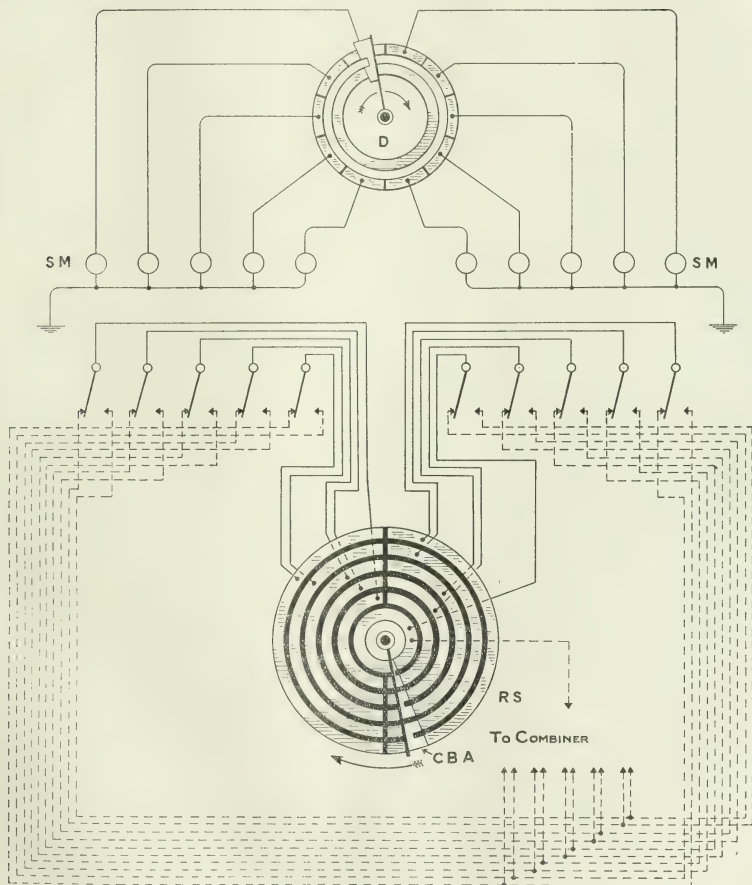


FIG. 64.—Illustrating complete overlap of setting and printing cycles (Kirk Himrod).

rotates with the distributor-brush arm. Its function is to disconnect all the armatures of either group of setting relays while these are being set, and so to prevent their interfering with the printing from the group which has just been set. An electrical combiner of the class shown in Fig. 24 can be used, but it must run at twice the distributor speed since two letters are printed per revolution of the distributor.

Using such a combiner as Fig. 24 and having two sets of segments and a type-wheel with two complete fields of type, the rotary switch of Fig. 64 could be dispensed with and the combiner could then run with the distributor and at the same speed.

#### PART IV.

**Synchronism.** The flywheel. Phase-swinging. Damping devices. Methods of giving a motor a periodic time. Theory of Baudot governor. The phonic wheel. Properties of vibrating reeds. Control of phase over a line wire. Correction at more than one point. Murray's 1-segment correction arrangement. Speed correction. Clock-hand correction. Correction from the signals; Picard, Dixon, and Rainey's methods. Idle signal. Rectification. Synchronism between printer and distributor units.

All modern high-capacity printing-telegraph systems depend for their operation on the satisfactory maintenance of identical speed and phase between two rotating mechanisms at each end of the line.

There are two broad aspects into which the subject may be divided, viz.

- (1) Means for obtaining uniform angular velocity of the rotary device.
- (2) Automatic methods of securing and maintaining a definite phase relationship between the rotating means at each end of the line.

The synchronism may also be considered as (a) main, and (b) local. Under the first sub-heading falls the synchronism between two distributors with an intervening line wire; while the second refers to the synchronism between a distributor and its local printing units, all on the same table or adjacent to one another.

The conditions affecting the maintenance of main and local synchronism are widely different.

It is a comparatively easy matter to secure synchronism between two rotating bodies fixed on the same instrument table, but when these are controlled through a line wire which will be subject to interruptions and the constants of which may vary from hour to hour, disturbances are bound to arise. On the other hand, the work of driving distributor brushes is constant, except for non-periodic effects such as failure of lubrication or dust in bearings. With a printer unit, however, the necessity for printing, paper feeding, and change of case, will throw extra work on the printer motor and render this liable to get out of step with its controlling distributor.

To secure the necessary identity of angular velocity, the first thing to be done is to adopt a motor either having a periodic characteristic or provided with some form of governor, rendering it isochronous. This by itself is not

sufficient. Taking a brush speed of 4 r.p.m., the contact arm of a distributor revolves 14,000 times as fast as the minute hand of a clock, so that an extremely small difference in the going rate of two distributors would accumulate very rapidly if means were not provided for intermittently correcting the shift of phase before this becomes serious.

Should the two towns between which communication is desired have alternating-current supplies of standard frequency, then, by using 2-pole synchronous motors and gearing down, identical speeds and phase could be maintained. This points to distribution of standard-frequency alternating current over a network of special wires to centres at which distributors are to be equipped, a suggestion which has actually been made by Crehore; but the capital cost of such a scheme would render it prohibitive, while the periods of zero current would be dangerous. It would be better to use two earthed batteries oppositely connected to line through a 2-part commutator. In any case, other and more convenient measures are available.

Until comparatively recently, independent weight motors were employed for both distributor and printer unit-drives, but such motors are fast disappearing and need not be considered. Shunt-wound electrical motors worked off the power mains are now generally used. Provided with a flywheel of suitable energy-storing capacity such an arrangement forms a very steady drive, though not in itself sufficiently precise for time-dividing of the required accuracy.

A flywheel cannot alone give any periodic characteristic to a revolving system to which it may be attached. It acts only to keep variation of angular velocity within certain limits. This it does by taking up and storing any excess energy tending to accelerate the moving system, and this storage can only take place by the flywheel itself accelerating slightly. When the accelerating tendency is removed and the angular velocity approaches the normal, the surplus energy stored in the flywheel is given up, retarding the return to normal speed. Thus instead of a quick variation from normal speed and an equally quick return, there is a smaller variation spread over a longer time. This swinging out of phase and back is slow and can be kept down to a very small amount just as much as the flywheel capacity of the system is increased. If, however, we have a flywheel with a large moment of inertia, it takes a long time to bring the whole system up to speed; rather a serious matter in the event of a temporary stoppage, as the whole printing system is in a state of enforced rest, and delay to traffic accumulates.

Phase oscillation may be checked considerably by viscous damping devices.

Diagrams A, B, and C, Fig. 65, represent devices which have been used for this purpose. Diagram A is a flywheel provided with a hollow rim containing mercury. The action is as follows:—

The centrifugal force exerted on the mercury presses this against the outer rim of the container. Due to its inertia, the mercury takes time to accelerate, but the friction exerted between it and the rim gradually brings it up to speed, until it is finally at rest relatively to the rim. The work expended on the mercury is not stored as kinetic energy, but is lost by friction. If, now, the moving system

is subject to oscillation, the magnitude of such oscillations is damped by the friction brought into play.

Diagram B shows an alternative arrangement in which a circular mass *M* is placed in the hollow wheel, *M* being

a circular rubber tube *T*. Under the action of centrifugal force the tube expands into the wedge-shaped annular space formed in the walls of the containing wheel. This wheel has thus the peculiarity that it possesses, in addition to

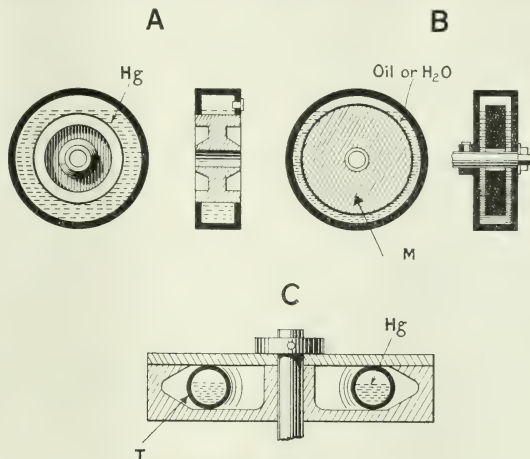


FIG. 65.—Various forms of viscous damping devices.

loose on the shaft. Oil or water can then be used in place of mercury.

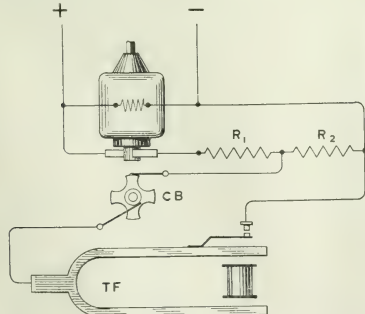


FIG. 66.—"Interfering contact" method of motor speed-control.

Diagram C illustrates a novel flywheel invented by Howgrave Graham. Here the mercury is contained in

the damping feature, a variable moment of inertia, and it can take care of very sudden and relatively great variations.

Fig. 66 is an "interfering contact" method of governing the speed of an ordinary continuous-current motor. The armature is put across the main in series with two resistances  $R_1$  and  $R_2$ . These resistances are so chosen that when both are in circuit the motor speed is lower than required.  $R_1$  is periodically short-circuited through the tuning fork *TF* and contact breaker *CB* driven by the motor, thus bringing down the average resistance. This circuit is opened and closed at two places. If the period of "make" at both fork and contact breaker occurs simultaneously, the short-circuiting effect is a maximum and the motor accelerates. If the periods of "make" are out of phase, the motor slows down.  $R_1$  and  $R_2$  are so adjusted that the desired speed is constantly obtained.

The most satisfactory method of obtaining a motor with a time characteristic is to use the so-called "phonic wheel" of Rayleigh and La Cour. This motor, which is really a reversed inductor alternator used as a synchronous motor, consists (Fig. 67) of a toothed iron wheel *W*, and rotation is secured by the alternate action of two magnets  $M_1$  and  $M_2$  energized by the battery *MB* through two contacts *MCS* on a vibrating reed. The reed is tuned to a definite frequency by means of a sliding weight *SW*, and is kept in vibration by a separate battery *RB*, the circuit of which is closed through a driving magnet *RM*

and the contact RMC. It is important that this circuit should be distinct from the motor-magnet circuit of the wheel, otherwise reactions are set up interfering with the free vibration of the reed, and the speed is consequently very variable.

Diagrams A, B, and C, Fig. 68, give three positions of the wheel at the moment when the driving impulse exists. In case A clearly no torque can result and only existing momentum will carry the wheel on. Case B illustrates the wheel running fast, and the impulse will tend to retard this. Diagram C shows the reverse case to B and the

bearings, though the latter get over lubrication troubles. It must not be forgotten that the distributor brushes exert a damping influence. A reed of the type shown will, if made of invar steel, remain very nearly isochronous over a wide range of current values, and the combination of Fig. 67 is proving in actual practice a most satisfactory one, easy to adjust and capable of steady and prolonged action.

Fig. 69 illustrates a modification in the vibrating reed developed by Murray. Buffer springs BS are placed on each side of the reed and store up the kinetic energy of the latter when this is vibrating on each side of its mid position, returning this energy to the reed as it moves away again. As a result of this construction, the rate of

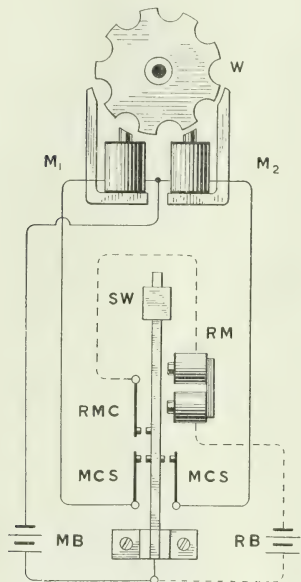


FIG. 67.—Phonic-wheel motor controlled by vibrating reed.

impulse has an accelerating tendency. So long as the reed vibrates freely at a constant rate, the motor will have a mean speed, above and below which it will oscillate very slightly. The current impulses should be powerful and as short as possible, and while the wheel may have some fly-wheel capacity, this must not be too great or the wheel simply oscillates and will not rotate. Eddy currents induced in the metal mass of the wheel act as a viscous damper and therefore have a steadying influence. Laminated wheels are a mistake, as the wheel is then too "free," and viscous dampers have to be added. For the same reasons, plain bearings are to be preferred to ball

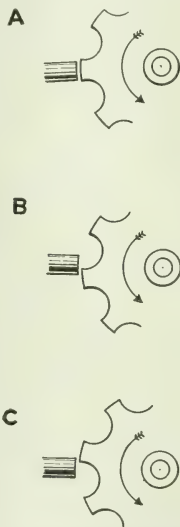


FIG. 68.—Illustrating self-regulating property of the phonic wheel.

vibration is made dependent on the current flowing in the driving magnet and increases with this. The curves in the lower part of the figure refer, A to the modified reed, and B to the reed of Fig. 67.

At about 200 milliamperes, the reed of Fig. 67 is seen to be practically isochronous while the speed of the modified reed goes up almost proportionately to the current. The ordinates represent revolutions per minute of the distributor.

If ordinary motors are used then any speed-governing arrangement should have some flywheel effect to give stability to the moving system, but phase swinging should

be kept within very narrow limits by so arranging matters that the surplus energy is not stored but degraded and so rendered non-returnable to the system.

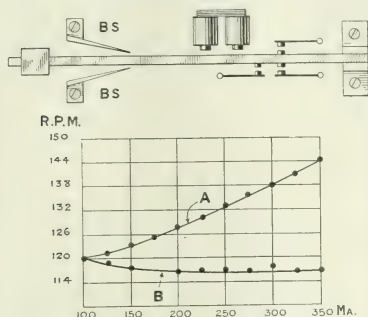


FIG. 69.—Murray form of vibrating reed and curves of performance.

Due to a gradual increase in friction the available energy to drive the rotating masses may be reduced, a condition contrary to that previously assumed. It is clear, therefore,

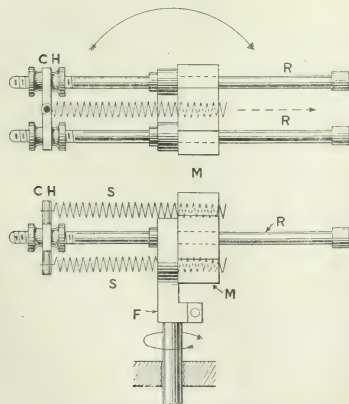


FIG. 70.—Plan and elevation of Baudot isochronous governor.

that some means must exist by which the deficit can be made up. What is wanted then, in order that the two opposite running conditions can be met, is to provide a load over and above the brush and motor friction loads,

so arranged that it can be removed to meet the second requirement.

Fig. 70 shows a plan and side elevation respectively of the isochronous governor used for the last 30 years on the Baudot printing telegraph. It consists of an octagonal brass mass *M*, weighing 35 grammes, mounted to slide on two rods *R* fixed in a fork *F* on the motor shaft. The mass *M* is controlled by two coiled springs fastened at one end to a crosshead *CH* fixed on the other end of the rods *R* and adjustable as to position by means of the lock nuts shown. The springs pass through two tapped holes in *M* to which they form bolts, and the spring tension can be adjusted by screwing the springs in or out of *M*, or by altering the position of *CH*. As *M* flies out in obedience to the centrifugal force, it exerts a bending moment on the motor shaft, since it is not counterbalanced, and the friction so developed constitutes a load on the motor

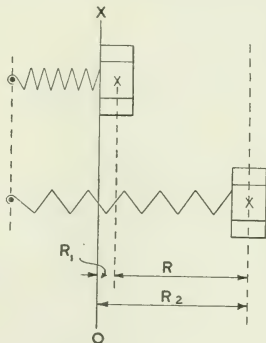


FIG. 71.—Conditions of adjustment of spring tension of Baudot governor.

which will vary directly as the radius of the circular path of *M*.

For any position of equilibrium at radius *R* the tension of the springs will be given by  $kR$ , where  $k$  is a constant; while the centrifugal force is expressed by  $m\omega^2 R$ ,  $m$  being the mass and  $\omega^2$  the square of the angular velocity. Equating these:

$$kR = m\omega^2 R \dots\dots\dots (1)$$

we get  $\omega^2 = k/m$  or  $\omega = \sqrt{k/m} \dots\dots\dots (2)$

Referring to Fig. 71 it is seen that if in the position of rest the spring is unstrained then, when the centre of gravity of the mass has moved to  $R_2$  the spring has only been stretched by an amount  $R$ , while the increase in the centrifugal force is represented by  $R_2$ . Consequently the springs must be given an initial tension corresponding to the difference, i.e.  $R_2 - R = R_1$ , in order that (2) shall hold and the governor be isochronous. If too much initial tension be given, the speed will diminish as the arc increases, the reverse holding for the opposite case.

This governor acts by supplying a permanent artificial load which will automatically increase or decrease in accordance with the needs of the moving system without introducing phase swinging. Actually, a small change in angular velocity is required in order that the governor can take up or release surplus energy; but the friction due to the governor is directly proportional to the centrifugal force; and this varies as the square of the angular velocity,

B, of which one is left disconnected and one earthed through a polarized relay P R.

If both distributor contact-brush arms arrive at 12 o'clock simultaneously, the positive transmitting battery at A will find no circuit at B, since the 12 o'clock segment there is disconnected. During their passage over the second segments of each pair, a negative current passes from the battery over the line and through P R, which remains in

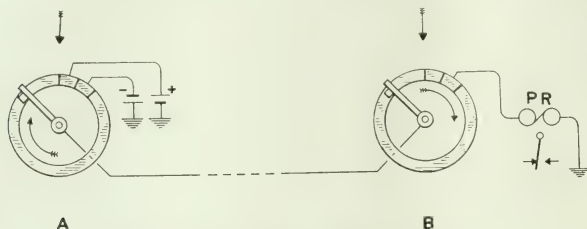


FIG. 72.—Method of transmitting and receiving correcting impulses.

so that a comparatively small change in the angular velocity is sufficient to bring about the required readjustment. The phonic wheel, of course, requires no such governor.

The next part of this section of the subject relates to methods by which the rotating mechanisms are kept in step with one another, a line wire intervening. As ex-

plained before, viz. with its armature on the left-hand contact. After one or two revolutions the distributor at B will have gained on A to such an extent that it will pass over its active receiving segment while A is passing over its 12 o'clock segment connected to the positive battery. The polarized relay P R will now move its armature on to its right-hand contact, and correction will be effected in

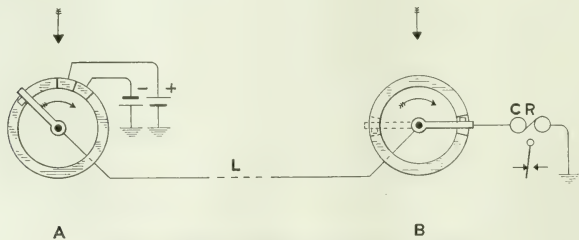


FIG. 73.—Effect of orientation of receiving correcting segment.

plained before, it is not possible to get two motors to run absolutely in step indefinitely, and therefore one motor is the "standard clock" of the system, the other being the secondary or controlled clock. The latter is arranged to run either faster or slower than the standard clock so that it gains or loses  $\frac{1}{2}$  to  $1\frac{1}{2}$  degrees per revolution, the exact figure depending upon circumstances. Referring to Fig. 72, A is the master or correcting distributor, and B the controlled or corrected distributor. Each distributor possesses a pair of correcting contacts, a transmitting pair at A connected to two earthed batteries, and the receiving pair at

some suitable manner so that the two brush arms start the next revolution in phase.

In the next figure, the effect of shifting the active correcting segment at station B is shown. If this contact is moved to 3 o'clock, the brush arm will ultimately "come in" at this point and the two arms will be  $90^\circ$  out of phase, B leading. If the contact is shifted counter-clockwise to 9 o'clock, B will come in  $90^\circ$  out of phase, lagging. Both of these positions would result in the wrong letter being printed, and it is evident that the position of the receiving correcting segment is critical. If, now, the line constants

alter so that the time of propagation of a signal is increased or reduced slightly, then correction will take place earlier or later at B and the phase will be automatically adjusted to the new conditions within certain limits. At the correcting station there is no such automatic compensation and the adjustment of the receiving segments or the orientation of these would have to be altered. The adjustment of the correcting is thus less stable than that at the corrected station.

Fig. 74 is similar to Fig. 72 except that two sets of transmitting and receiving correction segments are shown.

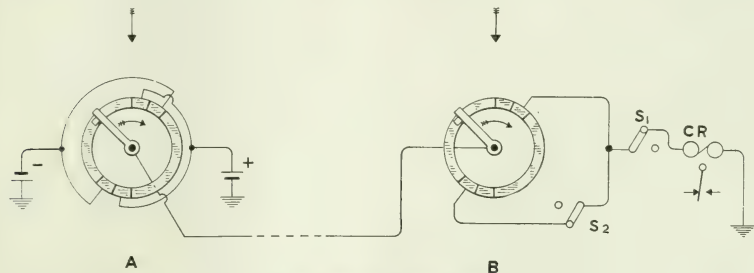


FIG. 74.—Methods of "finding the letter."

The effect of this arrangement is to offer two points at which the receiving distributor can come in. Supposing the brush B to be at 3 o'clock when the two brush arms start revolving, then it is clear that it will come in at 6 o'clock, since it has only got to gain  $90^\circ$  to do this, while to come in at 12 o'clock it has to gain  $270^\circ$ . If there were four points of correction, B can come in at any of the four, and, generally, with N correcting points there are the same number of possible positions for coming in, only one of which can be correct. In any but the correct position the wrong letter will be printed, and the means taken to prevent coming in out of phase is known as "finding the letter."

There are two ways of doing this. If switch  $S_2$  is opened it disconnects all but the 12 o'clock correction point, and B will come in at 12 o'clock just as in the case of Fig. 72. An alternative is to disconnect the correcting relay by switch  $S_1$  and to get station A to send a pre-arranged letter signal. The printer is then watched until this letter is correctly printed, and  $S_1$  is then closed again, correction taking place in a normal manner. If the speed difference at B is a suitable one, the same letter would be printed, with the correction inoperative, about 10 to 15 times, and in fact this is the usual method of observation by which the speed at station B is adjusted.

As we have seen, the distributor B is corrected when it has gained sufficiently on A to receive a portion of the positive correcting impulse. A certain length of contact is necessary in order that the correcting relay and its chain of mechanism may act in time to send the brush at B on its next revolution in correct phase relationship with A. This time of contact will vary with local conditions and, if

the battery voltage at B has fallen, a longer length of contact will be necessary. The two contacts at B are therefore merged into one large one less in length than the two and capable of some movement either with or against the clock. This is shown in Fig. 75, and the black shaded sector  $\theta$  represents the length of contact necessary for the correcting mechanism to act properly. If a longer time, say  $\theta_1$ , is necessary, the distributor will make one or two more revolutions before correction occurs and the brush arm will then slightly lead over that at A. This may be prevented by moving the contact C C counter-clockwise through the

angle  $\theta_1 - \theta$ , when matters will be set right. The line marking the coincidence of the end of the time of contact with the reversal from positive to negative of the correcting impulse, is termed by the French "point de repere"

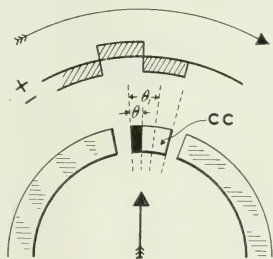


FIG. 75 — "Point de repere" on correction contact.

and by the Germans "merkpunkt," neither of which admits of a happy translation into English.

On circuits where saving of line time is of the utmost importance, as with long submarine cables, the two segments devoted to correction have an important bearing on the traffic-carrying capacity of the system. Arrangements are made to generate corrections from the signals

themselves, but an intermediate solution, requiring one segment only, has been proposed by Murray. Referring to Fig. 76, the fifth key of the transmitter is connected to the distributor as usual, but, in addition, it is connected to earth through a leak resistance and a polarized relay R. According to the position of the fifth key the relay reverses the battery connection to the segment 6, the transmitting correction segment, so that whatever impulse is sent to line on segment 5, it is immediately followed by an impulse of reversed sign. Correction at the receiving end is generated by means described later. One condition has to be met with this arrangement. When the distributors are

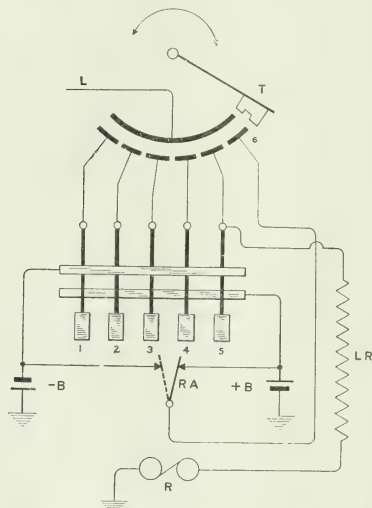


Fig. 76.—Transmitting circuit of Murray's 1-segment correction.

started up the corrected brush may come in at Y (Fig. 77) instead of X, and will then be out of phase and leading slightly. All that it is necessary to do at starting is to depress the transmitter keys immediately following the correcting segment at the sending station, thus obliterating the second correcting point Y, and in a few revolutions the corrected distributor will have gained one segment so that there is no longer any danger of its coming in at Y.

We have now to consider how the received correcting impulses are made effective at the receiving end.

Fig. 78 is an arrangement invented by Murray and others which has proved successful in actual use. M M are the motor magnets of a phonic wheel motor. When the correcting impulse is received the correcting relay CR is momentarily pulled up and disconnects the reed battery

RB. The speed of the reed is at once reduced in accordance with Fig. 68 and the motor will run slow, thus neutralizing any phase accumulation.

The next figure is due to Murray and is in successful operation. The line relay controls a relay P R suitably connected to the distributor for setting the five magnets corresponding to S M in Fig. 78. At the same time the governing relay G R is energized and during the transit time of its armature in passing from the back to the front stop the reed-driving circuit is disconnected. The period of disconnection is regulated by altering the distance apart of the contacts and consequently the transit time. This governing effect will take place at every reversal in the line current, so that correction may be generated from the signals themselves. The methods of Figs. 78 and 79 are speed-correcting arrangements.

The correcting impulse may be used to stop or step back slightly the contact-brush arm at the receiving station.

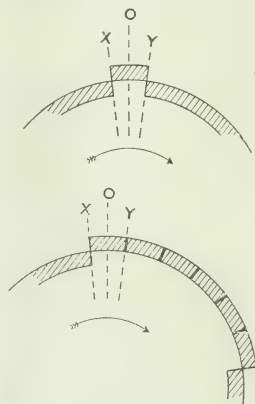


Fig. 77. Starting conditions of Murray's 1-segment correction.

Fig. 80 is one method of doing this. The phonic wheel PW is loose on the driving shaft and is connected to a free sleeve carrying a gear wheel  $GW_1$ . This is connected to a disc D, which is pinned to the shaft, through the intermediary of a star wheel SW and gear wheel  $GW_2$ . The star wheel is locked against rotation by a yielding jockey roller JR, the gearing thus forming a coupling between the motor and the shaft to be driven. If the jockey roller were removed, the star wheel and gearing would revolve idly and the shaft would be at rest. The correcting magnet CM when energized interposes a pin CP in the path of the star wheel, and as this latter comes round it is rotated through one tooth, uncoupling the motor from the shaft for an angle depending on the gear ratio and the number of teeth in the star wheel. A resetting cam RC on disc D

returns pin CP to normal when the star wheel has moved away. The correcting magnet has only to do the work of moving the light pin CP and the arrangement is thus very sensitive. It is the plan used in the Baudot.

latter, in pulling up, disconnects during its transit time the intermediate relay IR. The armature of the latter falls on its back contact, and if this occurs simultaneously with the passage of the contact-brush arm over two contacts

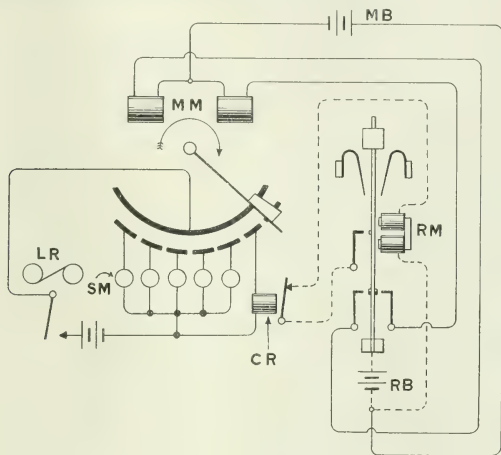


Fig. 78.—Receiving-end circuit for speed-correction control of motor.

The simple gear shown does not give fine enough correction and a compound train is required. The usual arrangement of the Baudot distributor is shown diagrammatically in Fig. 81. Star wheels having 9, 12, or 15 teeth are employed according to circumstances, giving

CC, a local corrector relay LCR is energized. The latter in pulling up is locked through a second winding by current from a battery passing through a contact on the correcting magnet CM through this magnet, through the armature of LCR and the locking winding of this

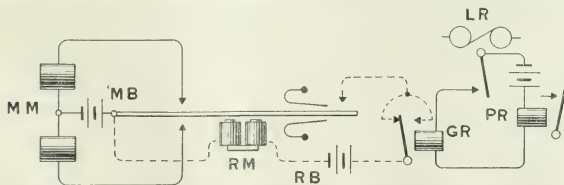


Fig. 79.—Speed-correction arrangement with corrections generated from the signals (Murray).

phase corrections of  $2\frac{1}{2}$ ,  $1\frac{2}{3}$ , and  $1\frac{1}{2}$  degrees respectively with the train shown. This method has come to be known as "clock hand" correction, and as distributors are time dividers, the expression seems apt.

Fig. 82 gives the receiving-end arrangements of Murray's 1-segment correction scheme. The line relay LR controls a printer relay and corrector relay CR. The

to earth. When the correcting magnet is operated, the locking circuit of LCR is broken down and everything is normal. Thus the transient correcting impulse is stored until it has done its work.

Correction of distributor speeds from the signals themselves was suggested by Murray in 1903, and about that time or a little later it was put into practice by Pierre

Picard on the Baudot installations working on the submarine cables between Marseilles and Algiers. Picard's arrangement is illustrated by Fig. 83, one sector only of the distributor being shown.

multiple to a switch relay SR, while the even-numbered ones are similarly connected to a condenser C and the armature of the switch relay SR. Switch relay SR controls a correcting relay CR.

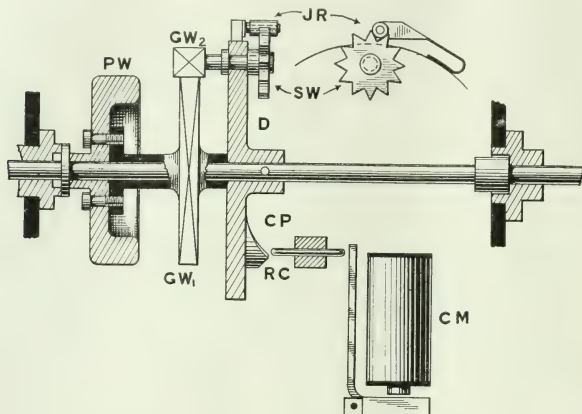


FIG. 80.—Murray-Baudot intermittent "step-back" correcting mechanism.

The connection from the armature of the line relay is divided, one branch going to a relay RR for setting the translator magnets (not shown) and the other to a con-

tinuous ring  $R_2$  of the distributor. Connected with this ring through the brushes is a ring  $R_1$  composed of five pairs of segments, each pair occupying an angle equal to that of one of the five setting magnet segments ring  $R_2$ . The odd-numbered segments of  $R_1$  are connected in

The outer ring A represents a letter signal when the distributor is in phase. The effect of the distributor gaining can be shown by displacing the letter signals in the direction of rotation (ring B). When in phase the switch relay will with the letter signal shown receive a positive current during the passage of the brushes over segment 1 of ring  $R_1$ , and the condenser C will have received a positive charge from segment No. 2. The switch relay will have moved its armature to the right, discharging C through relay CR, which is unaffected thereby as this relay requires positive current at its right-hand, or negative current at its left-hand terminals to move its armature from the positive shown. If the signal element is negative, SR does not move, and the negative discharge from C goes through CR at its right-hand terminal, which again is not affected. If the phase advances, SR will be actuated by a positive impulse and the condenser will be charged by a negative impulse or oppositely, and both these conditions are such as to operate CR. This remains on its active contact as long as the phase displacement persists, and the correcting magnet is operated when battery CB on ring 5 is connected through the brushes to CC.

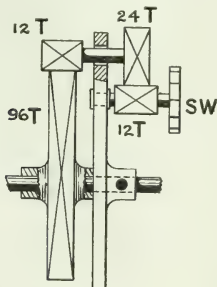


FIG. 81.—Correction train of Baudot distributor head.

tinuous ring  $R_2$  of the distributor. Connected with this ring through the brushes is a ring  $R_1$  composed of five pairs of segments, each pair occupying an angle equal to that of one of the five setting magnet segments ring  $R_2$ . The odd-numbered segments of  $R_1$  are connected in

Fig. 84 is a method invented by Dixon of the Western Electric Company. The left-hand contact of the line relay LR is connected to a transformer T, and when making or breaking this contact, in response to line signals, impulses are generated. The correcting relay CR is connected to a set of five shortened segments, displaced slightly in the direction of rotation. When the distributor is in phase,

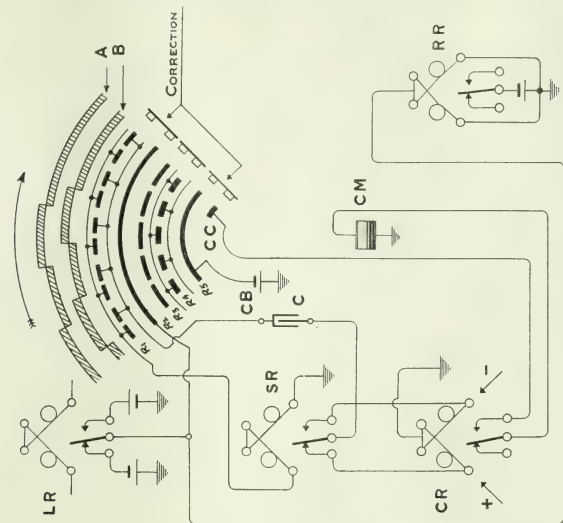


FIG. 83.—Receiving-end arrangement of Picard's method of generating correction from the signals.

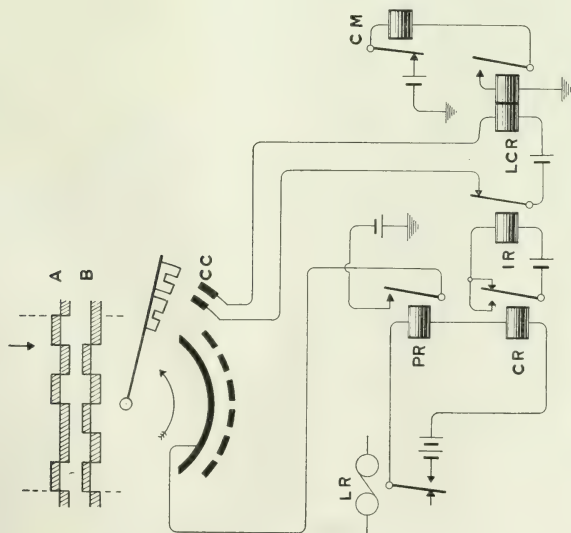


FIG. 82.—Receiving-end arrangement of Murray's 1-segment correction.



the impulses from T are ineffective as the brushes are not resting simultaneously on the shortened segments and the outer common ring connected to the relay CR at that instant of time. When, however, the phase has advanced, the impulses from T pass to CR and correction is effected.

The arrangement shown in Fig. 85 is due to Rainey, also of the Western Electric Company. It uses the five pairs of segments of Picard, but the method of generating the correcting impulse is different. The line relay controls a differentially-wound leak relay LR through resistances. When a change in polarity of the line current occurs, the armature of the line relay M L R reverses its position, and in doing so reverses also the leak relay, but there is a slight lag between the two so that, if the brushes are leading, a current pulse is transmitted from the odd-numbered correcting segment of the distributor to the correcting relay CR. This is energized and battery CB is applied to

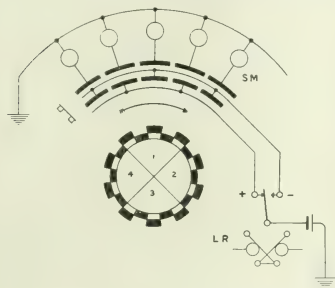


Fig. 86.—Rectification of "idle" signal (Picard).

the correcting magnet CM. An elastic buffer B is thus held against the fork and momentarily increases its rate of vibration, so speeding up the distributor. The correction persists until the distributor is in phase, when a further impulse occurs at the next change of polarity through an even-numbered segment, returning the correcting relay to normal and removing the buffer spring from the fork. When correction from the signals themselves is adopted, some departures from the ordinary are required at both transmitting and receiving ends of the wire.

The letter-finding arrangements of Fig. 74 are of course necessary, and means have also to be taken to ensure reversals of polarity automatically at the transmitting station to ensure correction when no traffic is being forwarded. This necessitates modifications at the receiving end so that the automatic idle signals do not operate the setting magnets of the printers at the receiving end.

Fig. 86 is an arrangement devised by Picard. The transmitting keys in each quadrant of the sending distributor are arranged to send out impulses automatically, as seen in the inner complete circle of the diagram. Considering sector No. 1, the first, third, and fifth impulses are positive, which corresponds ordinarily to the Baudot letter T, and this letter would be printed but for the rectification arrangement of the distributor segments. The

first, third, and fifth of these segments are connected to the local contact of the line relay against which the armature rests when a negative line current is received, while the second and fourth segments are connected to the positive local terminal. The line relay faithfully reproduces the line signal but cannot operate any of the setting magnets as, when it is traversed by a positive current, its positive local contact is disconnected, and vice versa. Picard was the first to apply the combination of idle signal with rectifying distributor contacts to correction from the signals. Murray, in his 1903 scheme for correcting multiplex distributors from the signals themselves, combined the idea of the idle signal with the method of correction from the signals employed by him in his automatic system. This is shown in Fig. 79.

Fig. 87 is identical in principle to Fig. 86, but the transmitters are so connected up that normally one transmitter

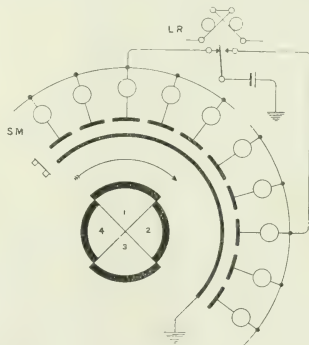


Fig. 87.—Western Union method of rectification of "idle" signal.

automatically sends positive, the next negative, and so on. Rectification is accomplished by connecting the setting magnets of sector 1 to the negative local contact, and of sector 2 to the positive local contact of the line relay L R. This method simplifies the wiring of the distributor. The diagram in the lower part of the figure shows the possible irregularity of the correcting impulses when generated from the signals themselves. In two letter signals, P and A, only one correcting impulse occurs, while there are no less than four in the next letter signal, U.

The connection between distributors and printing units calls for both isochronism and definite phase relationship, but, as previously pointed out, local synchronism is easier to maintain, as there is no intervening line wire.

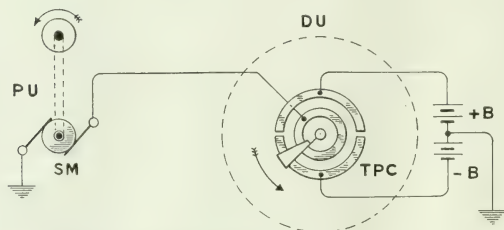


FIG. 88.—Early synchronizing scheme between printer and distributor units (Baudot).

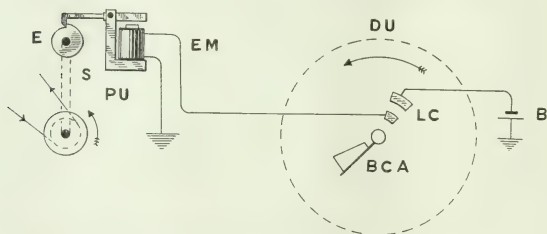


FIG. 89.—Synchronizing arrangement between printer and distributor units.

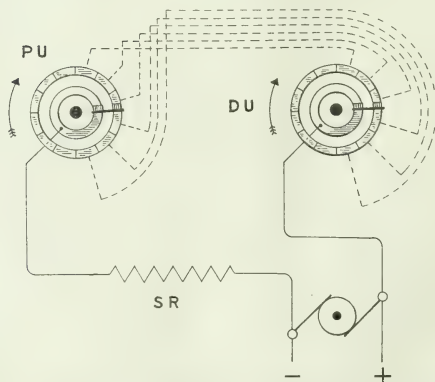


FIG. 90.—Synchronizing arrangement between distributor and printer units (Potts).

Fig. 88 is one of the earliest solutions by Baudot, although not, the author believes, put into practice. On the distributor unit DU is fitted a 2-part commutator TPC connected to a divided battery. The printer unit PU is driven by a 2-pole synchronous motor SM and must therefore run in phase with the distributor.

In Fig. 89 the printer unit is driven by a slipping drive and is normally held against rotation by a 1-revolution

the brushes come into phase. The smaller the number of segments, the greater is the phase difference before correction.

Fig. 91 is the arrangement at present in use on all Baudot installations. The printer shaft carries a cam C which depresses a lever CL, closing a pair of contact springs CS. When this action coincides with the closure of two contacts LC on the distributor, a circuit is com-

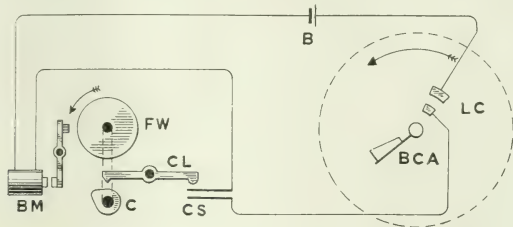


FIG. 91.—Present-day synchronizing arrangement between printer and distributor units (Baudot).

escapement E mounted on the same shaft S and controlled by an electromagnet E M. When the setting cycle is completed, a contact LC on the distributor is closed by brush B C A, and battery B releases the escapement, allowing the printer unit to make one revolution. The printer should be driven at a slightly higher rate than the distributor.

An interesting phase- and speed-control device is that of Fig. 90, invented by Dr. Potts who was closely connected with the Rowland system. Two identical commutators

completed for battery B through a brake magnet E M, which applies a brake brush to the rim of the flywheel, thus reducing the speed of the printer. The printer unit is arranged to run 3 to 4 per cent faster than the distributor unit, and automatic phase finding is thus secured.

Momentary phase swinging of a distributor may occur at times, and unless means are taken to obviate its ill effects the wrong letter is liable to be printed.

In Fig. 92, diagram A, the letter signal  $+-+--$  is

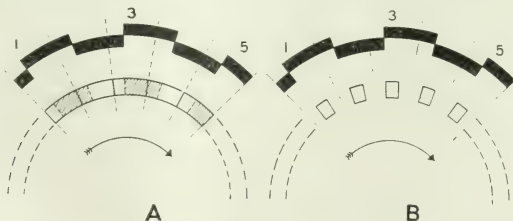


FIG. 92.—Effect of shortened distributor segments on phase swinging.

are fixed on the printer and distributor, consisting of an inner complete ring and an outer ring composed of a certain number of segments. Similar segments of each commutator are connected together, but in the diagram only half of the segments are so shown. So long as the two sets of brushes are on similar segments, *i.e.* in phase, a shunt resistance SR is placed around the motor armature driving the printer unit P U. This strengthens the fields, and the motor runs at a lower speed than it would do if unshunted. As soon as either brush gets out of phase, the shunt circuit is broken and the motor speeds up until

being received with the distributor brush one-third of a segment in advance. This is represented by shifting the letter signal round clockwise on the segments, and it will be seen that the first impulse overlaps the second, and the third impulse the fourth segments. By adopting shortened segments, as shown in diagram B, the interference is prevented, and a distributor so equipped will give a greater margin against phase oscillations than if segments of the normal size were provided. This arrangement has been used on the Baudot for many years, and the new multiplex systems have all adopted it.

## PART V.

Automatic. Multiple. Circuit arrangements. Double or 2-way working. Orientation. Echelon working. Repeaters. Distortion of signals by introduction of repeaters. Re-transmitters. Repetition between quadruple and triple distributors. Series circuits. Forked circuits. Quadruple duplex.

We now have to consider the modern printing telegraph from the line-transmission standpoint.

If  $t$  is the duration of a letter signal and  $T$  the time taken mechanically to translate this, then (1)  $T$  may be very near

the collection of the tape from the individual perforator operators and its transmission is an operation additional to the work of perforation.

At the receiving end of the line, printing may be effected either directly or indirectly. Indirect translation depends upon the reception of the line signals in the form of a perforated tape and then the mechanical time taken has no influence on the line time. A perforated tape could also be used at the transmitting end, and is, in fact, used in the Murray and the Creed automatic systems, but a perforated tape is, after all, only a distributor of infinite radius, *i.e.* a

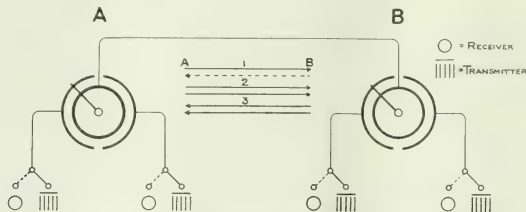


FIG. 93.—Diagram of "double" or 2-channel multiplex printing telegraph.

to  $t$ , in which case the apparatus is worked at high speed; or (2)  $T$  is much greater than  $t$  and represented by  $n t$ .

In the second case the line is not used for a time equal to  $(n-1)t$  and is available for the transmission of  $(n-1)$  signals from other transmitting points. For land lines  $n$  varies between two and six.

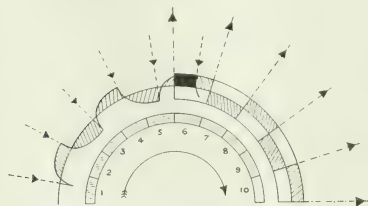


FIG. 94.—Interference between incoming and outgoing signals on long lines.

The high-speed 1-channel apparatus has come to be called automatic, and the multi-channel low-speed apparatus multiple or multiplex. So far as many details are concerned, the apparatus is identical and parts are interchangeable on both systems.

The high-speed or automatic printing telegraph consists of synchronously rotating distributors, a high-speed transmitter running in exact synchronism with its distributor, and keyboard perforators, which are identical in the two systems. The perforated tape from the independent perforators has to be placed in the transmitter by hand, and

rack. If perforated tape is used at both ends of the wire and rotary distributors are dispensed with, the perforations must be longitudinal and not cross perforated.

With direct printing, since the setting cycle must precede the printing cycle, then either line time must be lost by an amount equal to that necessary for printing, or Kirk Himrod's plan of providing a complete overlap of the two cycles must be adopted. This is the course followed in the

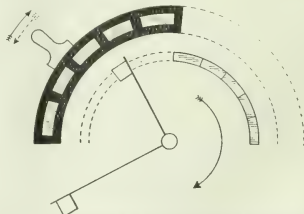


FIG. 95.—Transmitting and receiving sectors of distributor.

latest high-speed system using the 5-unit alphabet, *viz.* the Siemens and Halske. This apparatus is remarkable for the high printing speed obtained with a simple electromagnetic printing hammer striking a paper fillet against a type-wheel. Using the electrical combiner of Baudot and the Himrod overlap, no less than 1,000 letters per minute are printed perfectly free from blurring. At this speed the duration of the electrical contact to actuate the hammer is 0.0015 sec. only, and the mechanical time must not be greater than about half this. The method

of operating the electromagnet is, no doubt, largely responsible for the result, as the printing impulse is given by condenser discharge and so a very high initial electromotive force may be applied to the coil, causing a rapid rise in the exciting current, while the impulse is tapered and the hammer is not held against the type-wheel which, of course, would cause blurring. Worked at 40-50 words a minute per channel, as it would be on a multiplex

is not necessary to give diagrams for these since the arrangement will be obvious. In the case of the apparatus illustrated, the traffic possibilities are shown by the inset lines. Method 1 illustrates transmission from A to B with simultaneous transmission from B to A. During one half-revolution the printing magnets are being set, printing being effected during the next half-revolution. There is no need for printing and setting cycles to overlap since the printing

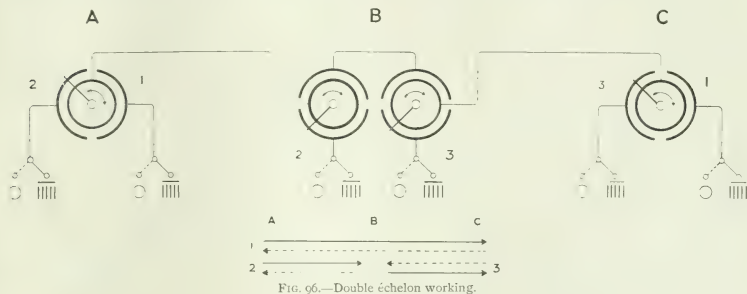


FIG. 96.—Double échelon working.

circuit, this tape printer would, the author thinks, be found to be much more durable than those at present in use, and although it represents a reversion to the early practice of Baudot, the author has adopted it for the printer he has designed for the Automatic Telephone Manufacturing Company. Adopting multiple transmission letter by

time in any multiple system does not involve waste of line time.

On lines of appreciable length there is a distinct interval of time between the instant at which the signal elements leave the transmitting end and their arrival with sufficient amplitude at the receiving end of the wire. This gives

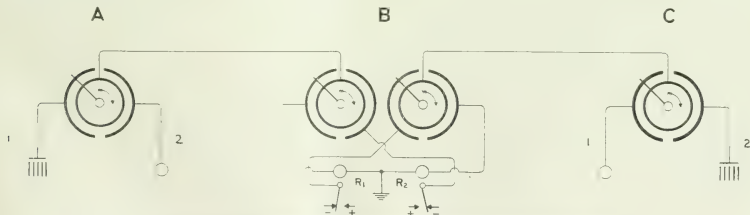


FIG. 97.—Multiplex-repeater with automatic reversal of direction of transmission.

letter by division of the line time, many traffic combinations will be found to be possible.

Fig. 93 represents symbolically a 2-way or double multiple system in which two messages are sent over one line wire L between stations A and B. The two distributors are each divided into two sectors, and with the contact-brush arms in phase with one another the line time is divided automatically, giving each operator possession in turn for the time required to transmit a letter signal.

Three, four, five, or six sectors might be used, permitting the transmission of signals from as many operators, but it

rise to interference between the incoming and outgoing currents at any station and special means have to be taken to combat the ill effects of retardation.

The left-hand sector of Fig. 94 is shown as receiving from the distant station, and the retardation is equal to half a segment, as indicated by shifting the letter signal round in a clockwise direction by this amount. The right-hand sector is occupied by outgoing signals. Due to the lag of the incoming signals, the last incoming impulse and the first outgoing impulse interfere with one another, and this is shown by the blackened area. Interference will be

prevented by disconnecting the sixth segment entirely and transmitting on the seventh to the eleventh segments. At the other end of the line a similar state of affairs will prevail, and generally if the retardation amounts to half, one, or  $N$  segments, then one, two, or  $2N$  segments must be left idle. If the lag is very serious, say three or four seg-

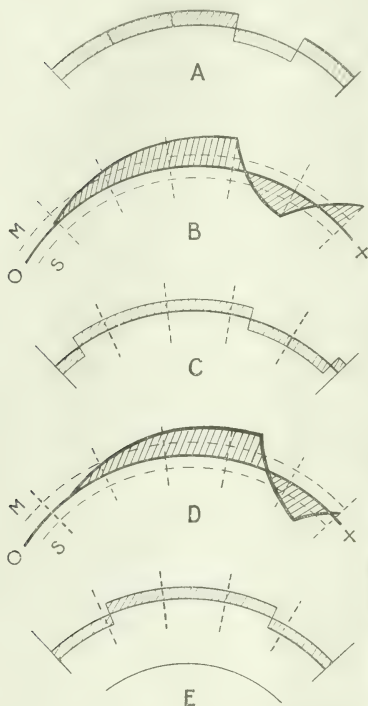


FIG. 98.—Distortion of signals when several repeaters are inserted.

ments, then the reduction in the traffic-carrying capacity of the line will make it advisable to use two lines, one for up traffic and the other for down.

An alternative is to use the differential or bridge duplex methods of working, when the lag will then no longer give rise to loss of line time, as the two periods of lag are no longer additive.

It is usual to mount the receiving segments on an insulating slide capable of slight rotation in either direction.

In this way the best setting of these may be obtained for a given lag, and also variations of lag may be met by means of this adjustment.

Orientation is only necessary for incoming signals, and to allow perfect freedom for effecting this the transmitting segments are usually on a separate ring. Fig. 95 makes this quite clear. The two brushes simultaneously engage the transmitting and receiving segments, transmission or reception being secured by a suitable switch.

Fig. 96 refers to what is known as double échelon working. Three stations are concerned, and by the successive switching effected at the distributors, communication is given between A and C, A and B, and B and C, in either direction. The intermediate station B acts as the correcting station for both A and C.

On long lines it is advantageous to divide the line into two or more parts, securing through-transmission by means of relay devices known as repeaters. The working speed on a line is inversely proportional to the square

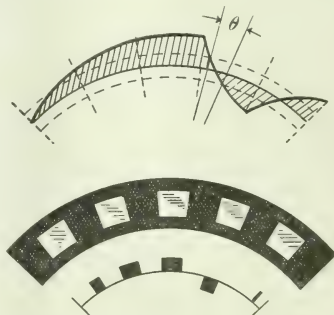


FIG. 99.—Effect of shortened segments on distorted signals.

of its length, so that by inserting a repeater in the middle of a long line, the speed is, theoretically, quadrupled.

Fig. 97 illustrates an arrangement of a multiple system giving direct communication between A and C with a repeater inserted at B. The apparatus at B consists of a synchronously rotating distributor with two faces, and during the passage of all brush arms over sector 1 transmission will take place in the direction A C, relay R<sub>1</sub> at B repeating the signals received from A through the right-hand distributor at B, and so on to C. A triple or quadruple circuit will differ only in the number of sectors on each distributor and the number of transmitters and receivers. It will be noticed that the direction of transmission is automatically reversed at B each half-revolution, and this is the function of the distributor there, which is, in fact, a rotary reversing switch.

With this repeater arrangement each sector has to be permanently assigned to either transmission or reception and cannot be used alternately.

Where more than one repeater is in circuit there is a tendency to serious distortion of signals, the distortion

increasing with each repeater station in circuit. In Fig. 98 A represents the square-topped waves corresponding to the letter signal + + - + as sent into the line from the distributor at the originating station. These are received at the first repeater in the form B owing to the characteristics of the intervening line wire. Dotted lines M and S equidistant from the line of zero current O X represent the current values, positive or negative, necessary to move the relay armature at the repeater. C is therefore the

duced, though the fourth, and still more so the fifth, are attenuated and the latter are probably not workable, but the exaggeration from the practical shows very clearly the rectifying effect of the special segments. The fifth impulse would probably disappear entirely if a further re-transmission took place.

An additional advantage of the shortened segments lies in the protection they afford from line disturbances at times when the line current falls below that necessary to

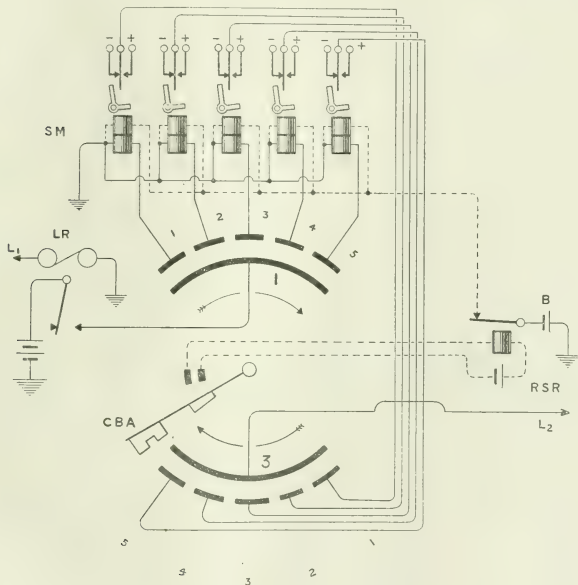


FIG. 100.—Principle of the re-transmitter.

flat-topped wave sent out by the relay armature at the first repeater station. Assume that the next section of line is equal in all respects to the first; its arrival curve may be taken to be the same, and D and E represent respectively the arriving and re-transmitted waves. E should be compared with A. The state of affairs in actual practice would have been improved, of course, by suitable orientation, and by inserting at least one repeater in the first section of the line before reaching the point at which the arrival curve is given by B. Employing shortened segments at the receiving point so as to select the middle portion of each signalling impulse, we get the result shown at the bottom of Fig. 99. Here all the impulses are repro-

operate the line relay. A region of possible disturbance is indicated by  $\theta$  on the diagram.

It is evident that for very long lines re-transmission by relays with a minimum number of repeating points would seriously reduce the speed; the French Administration have therefore introduced an apparatus for repeating purposes which they call a re-transmitter, whereby the signals are repeated onward in as perfect a form as that in which they left the originating transmitter. Fig. 100 represents in principle this device. Sectors 1 and 3 of the distributor at the repeating station are used, 1 for incoming signals from the transmitting, and 3 for outgoing signals to the distant receiving station, respectively. During the

passage of the contact-brush arm over segments 1 to 5 of sector 1, five setting magnets SM are operated in accordance with the letter signal received. These magnets have two windings and are arranged for marginal operation, so that the signal is stored although the setting currents are transient. Each setting magnet controls five contact

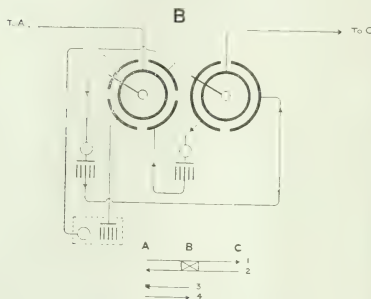


FIG. 101.—Repetition between quadruple and double distributors by means of re-transmitters.

springs which represent the transmitter at the originating station. The re-transmitter is, in fact, a remotely controlled transmitter, and it may be remarked that it can be replaced by a receiving perforator controlled by sector 1, the tape being placed in an automatic transmitter for re-transmission over the second section of the line. In this case, if required, the further section of the line may be

station. After re-transmission, the re-set relay RSR is energized through contacts on the distributor, and battery B is momentarily disconnected, the magnets SM thereby releasing their armatures which go to normal ready for the next signal. The phase difference allowable between the setting and re-transmitting cycles greatly increases the flexibility of the multiple printing telegraph, as the examples following clearly show.

Using re-transmitters, it is possible to repeat in both directions from circuit-worked quadruple to a 2-way or double. In Fig. 101 B is the repeater station intermediate to A and C, and is provided with auto-reversing distributors. In connecting a channel on the double to a channel on the quadruple, it is only necessary to observe that transmission from the one to the other does not take place in the similar semi-diameters of the two distributors. That is to say if the setting process occurs between  $0^\circ$  and  $180^\circ$ , the transmitting cycle must take place between  $180^\circ$  and  $360^\circ$ . Both the double and the quadruple revolve at the same speed. The storage feature of the re-transmitter makes this possible.

The succeeding illustration shows transmission on two channels from a quad to a triple.

This arrangement has been applied to the circuit from Paris to Algiers, Marseilles being the repeating station. Two cables across the Mediterranean are involved, one for the up and the other for the down traffic. This is necessary as the difference of phase due to line lag is about  $90^\circ$ , and 2-way working on a single cable would waste line time as only a single channel each way would be possible.

Transmission in the direction Paris-Marseilles is effected as follows:—From  $0^\circ$  to  $180^\circ$  the signals from Paris are set up on the re-transmitters  $R_1, R_2$ . Re-transmission takes place from  $R_1$  through the triple distributor connected to cable 1 during the time that the brushes sweep through the angle  $120^\circ$  to  $240^\circ$ , and from  $R_2$  through the angle  $240^\circ$

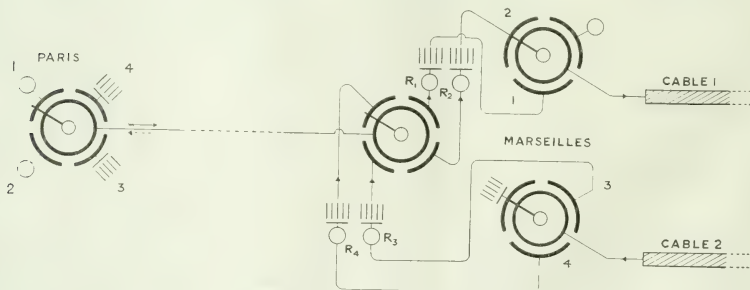


FIG. 102.—Repetition between quadruple and triple distributors by means of re-transmitters.

connected to a second distributor more or less independent, both as to speed and phase, of the distributor through which the signals are received.

When the contact-brush arm passes over sector 3 the stored signal is sent out and it is evident that this will be perfect and identical with the signals at the originating

to  $360^\circ$  respectively, reckoned from 12 o'clock. Signals from Algiers are received on cable 2, and the phase relation between the setting and re-transmitting cycles will be evident from the explanation above.

A third cable is used for traffic in alternate directions between Marseilles and Algiers, and by means of appro-

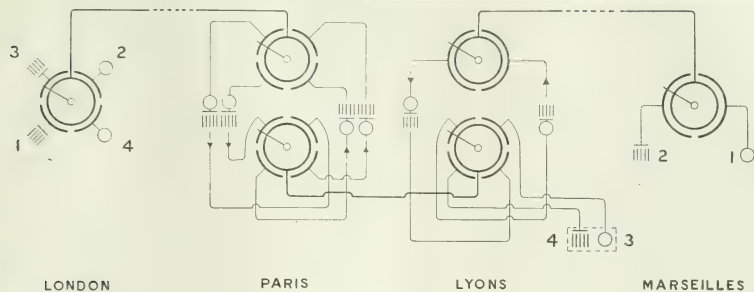


FIG. 103.—Long-distance "series" working by means of re-transmitters.

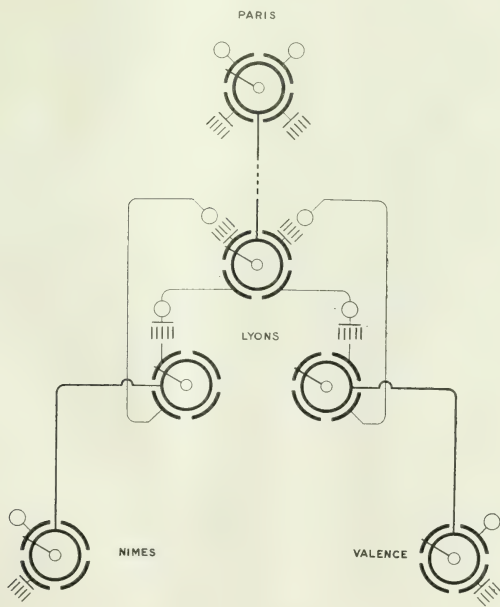


FIG. 104.—Method of working "forked" circuits by means of re-transmitters.

private switches can be used to furnish further channels to and from Paris.

Fig. 103 gives details of a series circuit of a type widely used by the French Administration for international circuits, and is rendered possible by re-transmitters. The traffic-carrying channels are clearly seen from the lower diagram. The distributor at Paris has two faces, both quadruple, while that at Lyons is a combined double and quadruple. Paris corrects London and Lyons, and the latter corrects Marseilles.

The installation of Fig. 104 is a forked circuit, Paris securing two channels, one each way to Nimes and the same facilities to Valence. Lyons, the repeating station, corrects all distributors. The sectors at Lyons shown as unused are actually devoted to communication between Lyons and the two terminal stations.

A type of circuit which is coming more and more into use, largely due to the successful pioneer work of Mr. A. C. Booth, is the quadruple duplex, a diagram of which is

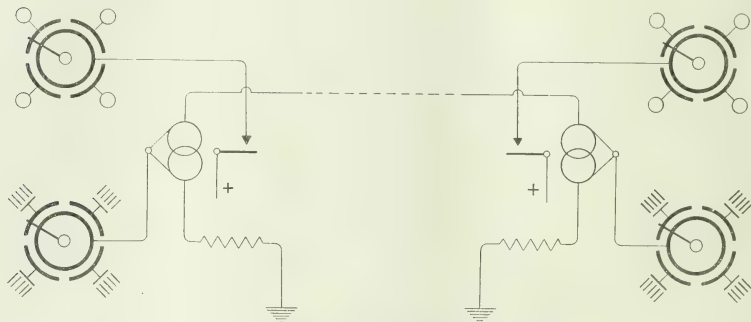


FIG. 105.—General arrangement of quadruple-duplex circuit.

given in Fig. 105. It scarcely requires any explanation. The capacity of a wire is at once doubled, and as previously explained 2-way working does not, with this arrangement, involve loss of line time.

If time and space had allowed, many more interesting arrangements might have been described, showing the extreme flexibility of the modern multiple printing telegraph, but the examples selected will convey a very fair idea.

#### CONCLUSION.

The art of type-printing telegraphy has now reached such a stage of development that it is possible to answer many questions hitherto shrouded in the mists of doubt.

The last few years have seen the triumphant advance of the 5-unit equal-letter alphabet.

For military reasons, and also in the field of wireless telegraphy, hand Morse working will never entirely disappear, as a fairly large reserve of skilled Morse operators

will have to be at the disposal of the State in times of a national crisis such as the present.

The use of the Morse code for high-capacity printing telegraphs means delicately constructed machines at both ends of the line, and all the complexity imposed by the necessity for differential feed devices where unequal letter alphabets are adopted. This involves high first cost, and though no information is available, maintenance must be heavy also. The maximum possible speed, even with specially constructed translating mechanisms, is about 130 to 150 words per minute, and experience has shown that this speed is too high if the maintenance cost is to be kept down to a commercial figure. 120-130 words per minute represent the all-round useful speed, and this can easily be beaten by other methods. The same remarks largely apply to automatic systems using the 5-unit code.

High-capacity systems transmitting letter by letter at the low speed of 40 to 45 words per minute per printer unit can be of more robust construction, while the larger

number required makes it possible to adopt bulk methods of manufacture. The maintenance can thus be kept low, while the first cost will show a diminishing tendency as time goes on.

The adoption of type-printing telegraphs to large cable systems offers difficulties other than the mere engineering considerations. The ramifications of a large system like the Eastern would raise serious traffic problems and, whether these are insoluble or not, would require administrative knowledge which the author does not possess. It does appear to him, however, that for transoceanic traffic between two centres such as London and New York it should be possible from the traffic standpoint, and only the engineering aspect need be considered.

In recent years a number of highly efficient amplifying devices have been invented which considerably increase the speed of a cable core. Among these may be mentioned the magnifying relay due to Hurtleley and the jet relay invented by Axel Orling.

The drawback to all these devices lies in the fact that in

duplex working, owing to their extreme sensitiveness, it is not possible to secure a balance sufficiently precise to eliminate "jars" when the home transmitter is operated.

By applying the sine-wave method recently invented by Colonel Squier, the balancing trouble might be largely overcome, and the method would seem to have further advantages. Mechanical and electrical resonance could be taken advantage of.

A further drawback to the use of the magnifying relay is that by its use a long cable is made extremely sensitive to disturbances, which the syphon recorder does not reveal. Assuming, however, that with a moderate degree of magnification, the speed of a cable could be pushed up sufficiently to secure 25 words per minute per channel for a double duplex, it might be worth doing for special transatlantic work, such as "rush" stock traffic. Direct printing between the two points and the immediate handling of RQ's would make this, if practicable, very important to a cable administration. The adoption of a sine wave would allow of "x" stopper devices being applied at the receiver and thus perhaps increase the workable degree of magnification with any amplifying device.

The modern multiple system with keyboard perforators, automatic stop and start of transmitter, and distributor driven by phonic wheel, will work regularly at 160 to 180 words per minute, or 40 to 45 words per minute per channel. It seems possible that this is not the attainable limit. The Siemens automatic system, using the electrical combiner which Baudot discarded, can work at this speed on one channel only. Thus it is clear that printer units can be easily made having a higher speed than 40 to 45 words per minute, and the only barrier to speeding up channels or adopting a large number of channels is the transmission limit of the line. The main telegraph circuits of this country are now run underground and a lower speed of transmission is a necessary consequence.

An interesting experiment would be to connect a double duplex between London and Birmingham or London and Manchester, using electrical combiners, and to apply the vibrating relay of Gulstad in place of the standard Post Office main-line relay. The speed of transmission could then be raised to the maximum practicable, and the figures obtained would yield by simple calculation the number of channels at 40 to 45 words per minute which could be worked on the circuit under test.

Another aspect, and one of fundamental importance, is the precise means to be used for securing the synchronous operation of the distributors. Are we to have synchronizing impulses generated from the signals themselves, or to keep to the method of Baudot and his predecessors?

Generation of correcting impulses from the signals, as we have seen, sacrifices the automatic phase-finding property of the older scheme, and adds somewhat to the equipment and the work of adjustment.

It is also necessary to modify the transmitting arrangements so that correcting impulses are automatically sent when no transmission has taken place.

Where saving of line time is of the utmost importance, correction from the signals is an imperative necessity; but, except for extremely long land lines of the trans-

continental order and long ocean cables, it is doubtful if it is worth while abandoning the simpler and automatic method of coming into phase, which is a valuable feature in the case of news circuits and forked and series working.

The only other advantage of correction generated from the signals lies in any possibility of more precise synchronism, and this appears more than doubtful. It is a significant fact that the French, who have had more experience with synchronous multiple telegraphs than any other Administration in the world, and who have themselves, as we have seen, developed a method of correction from the signals, use it only on the Mediterranean cables, where saving of line time is of the utmost importance. On all the long international Baudot circuits, either direct, series, or forked, special segments are set apart for correcting purposes.

With the periodic clock-hand method of Baudot, synchronism may be made as precise as the most exacting practical requirements may demand by reducing the difference in speed of the two distributor motors, and correcting once per revolution, reducing the amount of "step back" of the planetary gear to suit the altered conditions.

The speed of the phonic wheel drive remains constant over wide ranges of current variation, and stroboscopic methods of speed adjustment enable fine speed differences to be readily secured. It must not be forgotten, however, that such speed differences involve increased length of time for "coming in."

Speed methods of correction are, in the author's view, to be regarded with suspicion. To borrow an analogy from Murray, we do not alter the going rate of our watches to correct for small deviations from standard time; we set the hands back. No clockmaker interferes with the power of his clock, he adjusts the resonant control. These are no visionary analogies, a distributor is a precise time divider, with a very high going rate.

The only other questions about which there have been differences of opinion, are matters of detail and not fundamental. They are

- (1) Page or tape printing?
- (2) Type-wheel or type-bar translators?

On the less important circuits, the type-wheel tape printer on account of its low first cost has, the author believes, a large field, and as the trunk circuits become equipped with high-capacity multiplex systems, the tape printer, especially if provided with re-perforators and arranged to be worked by perforated tape, will be increasingly adopted.

For the high-capacity circuit, the page printer, as it provides the maximum of labour saving, will hold undisputed sway.

That the type-bar page printer will come to be the pattern adopted, the author has very little doubt; not that satisfactory type-wheel page printers cannot be made, but typewriters being in commercial demand by the million, we have a translating mechanism much more durable than any type-wheel apparatus can possibly be, ready-made for us.

## DISCUSSION BEFORE THE INSTITUTION, 20 JANUARY, 1916.

Sir WILLIAM SLINGO: I desire to congratulate the author on the production of a paper that is second to none on the subject with which it deals. Printing telegraphs were among the earliest inventions, and I imagine that they did not find favour and were not brought into use for two reasons. The first I would ascribe to the conservatism that existed in the matter of handwriting. Twenty years ago no one regarded a printed telegram as being of anything like the same value as a message in the handwriting of the operator, which was some evidence that it had actually been transmitted and that somebody responsible had had something to do with it. Then there was the second point: every administration had the impression that it was necessary to keep an office copy. With the printing telegraph as then invented no office copy was available, one copy only being made. It would have been possible to run two slips through the receiving apparatus with a carbon ribbon between them, and thus to have made two copies, but it was quite enough to get the apparatus to do the work without introducing that additional complication. Press copying is a thing of comparatively recent date. I believe that even at the present moment in the United States it is the law that the office must keep a copy of every telegram which is sent out for delivery. We have, I am happy to say, got beyond that stage; we have got into the position that office copies are not essential, and therefore we are able to use the printing telegraph as freely as circumstances will permit. It is difficult to overestimate the advantages of printing telegraphs, particularly in these days when the elementary schools relegate the teaching of handwriting to a very subordinate position. There is also the saving of the time otherwise occupied in the process of transcription, and in a great variety of ways we certainly get a more economical output from a printing telegraph as compared with the hand-transcribing method. It may therefore be accepted that the printing telegraph has come to stay. It is not a question at the present time of printing versus non-printing telegraphs, but rather of high-speed automatic versus the multiplex. I think the battle around this question is almost as keen as the celebrated battle of the brakes in bygone years. On that account I am rather sorry to find no reference in the paper to the photographic printing systems. The Siemens system, for example, which was tried a few years ago in this country and which was capable of giving an output of 200 words a minute, only went out of use because when it was turned to duplex there was too great a drop in the speed, and it had the disadvantage of a 12-unit code. The Creed apparatus might perhaps have had a little more attention in the paper, particularly as it is at the present moment a very important instance of the high-speed automatic, and is doing us good service on circuits where it is particularly suitable. Then there is the Siemens automatic, which is referred to here and there in the paper, and in connection with which a few points might have been brought out. It is one of the very few novelties in the telegraphic world of German origin. I may say with a very strong conviction that during the whole period of the building up of modern telegraphy very little original work has come from Germany, and therefore

when we get an instrument like the Siemens automatic it is particularly welcome. It is at the same time exceptionally good. It has a very simple printing arrangement. No perforated slip is required at the receiving end, as in the Creed and other systems, and the perforator which is used for sending purposes can be applied also for receiving work when it is desired that the message shall be re-transmitted on another line. The combiner that is used is a revivification of the Baudot device which the author has described, and which he has adopted in his own excellent proposition. I say "proposition" because, although the instrument is on paper a good one, the author has not yet been able to supply us with one for inspection and trial. There is one other point about the Siemens apparatus to which I should like to refer, namely, that it allows on a single printer a working speed under actual commercial conditions of 166 words a minute, and that is better than we have been able to get from other instruments. Unfortunately we are unable to utilize the Siemens to any greater extent at the present time, but it has actually carried a great amount of traffic with a minimum amount of trouble and inconvenience. I am very pleased to notice the warning which the author gives on page 310 against the adoption of any system which introduces varying currents. I thoroughly endorse what he says in that respect, and if anything I can say will help to deter inventors from turning their attention in this direction, much time, money, and energy which might otherwise be wasted, will be saved. It is the very worst line which an inventor can follow with any hope of success. In Fig. 13 on page 315 I think the author has adopted a line of special pleading. He shows there that the Morse requires for the selected word 69 units, and that the 5-unit code requires only 35 units. I do not wish to deprecate in any way the 5-unit code, but I think it is scarcely fair to state that the Morse is twice as long as the 5-unit. It so happens in this particular case, because the author has chosen the word "London," which contains the long vowel, viz. the letter "O" twice. If he had taken the word "letter" he would not have required 69 units, but only 44 units, and that would have brought it more nearly into line with the 5-unit code. As a matter of fact, the average proportion is not 2 to 1, but 8 to 5. The author refers on page 321 to the automatic stop-and-start device, but I think he attaches rather too much value to it. We can use it or we can do without it. It is a very minute and problematical time-saver; it has a certain amount of convenience, but I believe that in the course of a week we should not save much more in the way of messages transmitted than by any other method. It is an advantage, but it is also an additional piece of apparatus. The paper feed ascribed to the Western Electric Company and shown in Fig. 53 on page 331 has been superseded by the apparatus that we are now using in the Post Office. The present arrangement is a horizontal roller placed immediately behind the printer, and it undoubtedly works satisfactorily. Then there is a reference on page 342 to flywheels at the receiving and sending ends of a circuit, and the author points out that the effect of those two wheels is to impair the sensitiveness on the part of the receiving apparatus.

It is noteworthy that the Siemens apparatus has no fly-wheel at the receiving end; the fly-wheel is at the sending end only, and the receiving apparatus comes into phase with remarkable promptitude. Reference is made on page 358 to a multiplex repeater, which is explained diagrammatically in Fig. 97. We do not need such complications for an A to C connection as shown in the diagram. So far as our multiplex apparatus is concerned we get all we require by an ordinary Wheatstone repeater placed in circuit. There is one point in connection with the author's "Conclusion" to which I should like to refer. He says: "The last few years have seen the triumphant advance of the 5-unit equal-letter alphabet." The 5-unit equal-letter alphabet is very good, but is very old, and I do not know that it has advanced very much. Should not the author have said that its existence has allowed the printing telegraph to advance triumphantly? I do not think electrical engineers would agree that coal has shown a triumphant advance because electric tramways are seen on our streets and make use of the coal consumed for driving them. Then the author says in the next paragraph: "For military reasons, and also in the field of wireless telegraphy, hand Morse working will never entirely disappear, as a fairly large reserve of skilled Morse operators will have to be at the disposal of the State in times of a national crisis such as the present." I do not suppose for a moment that the Post Office administration will maintain a reserve of Morse operators in order to prepare for the next possible war. The military authorities will have to look after their Morse operators if they want them. They may not want them when the next war comes along; the Morse may have been superseded for military purposes, but I must say that Morse operators will always be necessary so long as we have multiplex or high-speed apparatus. We must have Morse operators because on every such circuit there are conversations taking place during the balancing and preparatory periods when all the work is done by means of the Morse. I agree with the author concerning the difficulties attending the use of the Morse code for high-speed printers, and no doubt this is the reason why we have only one instance of this class of apparatus; but I do not think he is quite right in saying that the speed of the 5-unit code is limited to 130 to 150 (which is a liberal figure for the other type), because, as I have already said, we are getting 166 regularly out of one of them. I do not know what traffic problem the author is referring to later on when he speaks of the Eastern Company's system. (Mr. Harrison: Check numbering.) There is this about it, that the Eastern Company have one line from London to Alexandria in which they have abandoned the cable code and are using the Morse code with Creed apparatus. The Heurtley and Orling relays are promising, but we must not forget that in introducing a very sensitive device on a line in order that it may respond to very feeble signals we are at the same time introducing a device which will respond to feeble disturbances, and all cables—the longer ones particularly—are subject to disturbances, and I am afraid it will be a long time before we are able to work a printing telegraph through an Atlantic cable. Nevertheless any device which will even only fractionally increase the output of a submarine cable is bound to be adopted, and that quite independently of the amount or value of the apparatus which would have to be scrapped

in consequence. So far as land lines are concerned it may be said that the limiting point in the carrying capacity of short lines is the speed at which the instrument will work, but it is usually more economical to work such lines with comparatively slow apparatus and if necessary increase the number of lines. On long lines the increase in output due to extra-high-speed instruments is not equal to that which can be obtained by cutting the line and inserting a repeater at an intermediate point and using ordinary high-speed instruments. The line, in fact, determines the working speed. Wheatstone apparatus can work at higher speeds than long lines will carry, and there is therefore no advantage in increasing the speed. There is the further point that a circuit working at extra high speed could not be continuously fed with traffic. If a London-Liverpool duplex circuit were provided to work at 400 words per minute each way, it would have a carrying capacity of about 1,600 messages per hour. The peak-hour load is about 600 messages. Reference is made to the Gulstad relay, which is, however, at present unobtainable. The principle is admittedly good, and a new form has been designed and brought into use by the Post Office engineers which has the advantage of being available for either differential or bridge duplex working. The new relay will also be placed on the London-Glasgow quadruple Baudot circuit, and it is possible that the repeater now in use at Warrington will as a consequence be released. The particular experiment suggested by the author can be equally well carried out with Wheatstone apparatus, and the result multiplied out to ascertain the capability of the relay when used on multiplex circuits. Experiments have actually been made with quadruple multiplex apparatus using ordinary Post Office relays on underground lines, and it has been ascertained that 300 miles is the greatest length through which a speed of 50 words per minute per channel can be obtained. The signals were not good enough for ordinary working. I am not quite in agreement with the author on the question of synchronizing impulses. The Western Electric and Siemens instruments correct satisfactorily from the signals. The line is the most valuable part of a circuit and line-time saving is therefore essential. The saving by correcting from signals is appreciable and is consequently commendable. The reference to the French practice is not quite happy. France has never until within the last few months adopted duplex on the Baudot system. It is essentially a British application. If the French should adopt an underground system the probability is that they will endeavour to get the most out of their lines and will therefore go in for correcting from signals as well as for duplex working. Concerning page-versus tape-printing, I think the former which is used on the Murray and Western Electric instruments will in the end be found more suitable than the latter. It permits a considerable saving in stationery and is more economical in time. The difficulty due to known typing errors has been overcome. The type-bar is metallic and is superior to vulcanized rubber type-wheels, which frequently get broken and which if not broken wear out somewhat rapidly. But metallic type-wheels are quite efficient and have done good service in the Hughes, Siemens, and Baudot apparatus. This form is also used in the Cardwell instrument, a new short-line page printer very robust in construction which would

Sir William  
Slingo.

Sir William  
Slingo.  
Colonel  
Squier.

be of considerable service if the cost should prove to be moderate.

Colonel G. O. SQUIER : In thinking over something pertinent which might be said on this subject, and in view of the unusual number of telegraph experts present this evening, it has occurred to me that it would be best, in an effort to contribute perhaps something constructive, to call attention to the desirability at the present time of a careful stock-taking of the whole of telegraphy, from beginning to end, to see where we stand in the matter, and perchance to profit by certain tendencies now developing. In the newest branch of telegraphy, the so-called wireless telegraphy, we find that during the past 16 years, due to the way in which the subject has appealed to the imagination of all classes, some of the best-trained minds of each country, as well as a large number of practical engineers and a host of amateurs, have been attracted to assist in the solution of the manifold problems presented. This has resulted in the accumulation of a vast storehouse of engineering and physical data traceable directly or indirectly to this new and fascinating field. In this phenomenal development we see a good example of the wisdom of borrowing freely from other arts whatever is necessary for our purposes. The radio engineer has taken from the power engineer his low-frequency dynamos, power transformers, etc.; from the older art of wire telegraphy, keys, sounders, buzzers, Morse printers, choke coils, etc.; from the pure physicist, some of the most refined of his laboratory efforts, and now he threatens to appropriate Mr. Orling's long-cable jet relay, and Mr. Heurtley's cable magnifier. In addition, he has completely broken down the barriers between telegraphy and telephony, since in his hands each radio telegraph circuit becomes a telephone circuit by merely substituting the microphone for the telegraph key. I do not criticize this procedure, I commend it to members' serious attention. We find, in fact, that the re-borrowing process has already begun, and in the case of the recent inauguration of the New York-San Francisco telephone line, one of the principal factors in final success was due to an instrument originally developed as a receiver for radio telegraphy and telephony. It would appear that the word "wireless" is an unfortunate one from an engineering standpoint. The radio engineer is strictly limited in all his efforts to the propagation of alternating currents either within, upon, or along metallic wires, and none of his skill can change in the slightest degree the character of the ethereal part of the circuit between the antennæ. The moment the energy breaks away from wires he has lost all control until, or unless, it again comes in contact with other wires. On this view, therefore, radio engineering appears merely as an extension of the much older art of wire telegraphy, and there is no such thing as wireless telegraphy. A radio station may exhibit within itself the whole range of phenomena from an alternating current of low frequency propagated by conduction through metal, as is the case in the primary generator circuit, up to this same energy transformed into an alternating current flowing along the wires of the antenna at a frequency which makes the radiation factor, instead of the conduction factor, the predominant one. It seems possible that some day we may be able to have a perfectly general telegraph equation which will contain sufficient terms to apply to any case from pure radio transmission, through wire practice,

down to ocean cable telegraphy, by substituting the proper value of  $n$ , the frequency. In such an equation, of course, the radiation terms would entirely disappear for low values of  $n$  and would reappear gradually as  $n$  is increased, until we come to the case of pure radio transmission. If we glance, for a moment, at the other end of the engineer's scale of possible frequencies, we go below the normal range of power frequencies, viz. 50 or 60 per second, and enter a region as yet wholly undeveloped. In this region falls the whole of the present ocean-cable practice. The strange thing about a 2,000-mile ocean cable constructed with practically no leakage or inductance is, that we arrive at a state of affairs very similar to the wireless case with antennæ, although the phenomenon is one of conduction and not radiation. In other words, it appears that in such a case we may consider short portions of the cable at the ends as a sort of "submarine conduction antennæ," which we design and use to launch the power on to its path across the ocean; and, on this view, the real ocean cable, which should be practically uniform throughout, begins 100 miles or so from shore at each end, and the end pieces should be considered more as a part of the station equipment than as part of the real ocean cable. These end pieces we can load with inductance and adjust to a maximum reading of a hot-wire ammeter exactly as we do with the radio antennæ. Furthermore, upon examining the essential transmitting circuits we find them an exact duplicate of the radio transmitting circuits, with the exception that the inductances and capacities required are microfarads and henries, instead of thousandths of a microfarad and millihenries. We see also that the amount of power we can put into this kind of antenna is directly proportional to the square of the voltage used, and therefore one of the first moves to be made for real progress is to design the end pieces to take much higher voltages, say from 100 to 500 volts at least, and then so distribute the copper and gutta-percha in the deep-sea portion of the cable as to produce minimum line loss in attenuation of the waves. As to the intermediate cases between ocean cables and pure radio telegraphy, which would include the whole of land-line telegraphy and telephony on pole lines, here we have the phenomena of conduction, reflection, and radiation in varying relations depending upon the value of the frequency employed. In land-line telegraph practice, however, we find that after over half a century the signals are still sent by making and breaking a battery current. At each break the line is charged with a large number of idle harmonics which upset the line apparatus generally, and as no single frequency is used in sending the signals themselves, we are barred from utilizing the principles of electrical and mechanical tuning and of automatic magnification which have done such great things for the radio engineer. Since we can scarcely hope to realize in telegraph practice Heaviside's "distortionless circuit," we can employ a "distortionless harmonic current" which, in the steady state, is propagated by any form of circuit with zero percentage change of shape and maximum efficiency of power transmission. As we pass immediately above ordinary telephonic frequencies on wires, we find a region of guided electric waves which are more or less linked with the conductor. It is not unreasonable to suppose that the telegraph engineer will in the future pay as much attention to

Colonel  
Squier.

the outside surface of his wires as he now does to the composition of the wires themselves. These surfaces may serve him to appropriate and control certain closely bounded regions of the free ether of space to create for him new channels of communication by guided electric waves. Our knowledge of skin effect should be extended by researches into the region bordering upon pure radiation, where we are dealing with a super-skin effect or film effect, and it seems not unlikely that we may be able ultimately to dip the wire or paint it with a metallic paint rich in unstable atoms or free electrons, which will tend to reduce the attenuation of the guided waves. Here the efforts of the master physicists should furnish a sure guide in the near future. These guided high-frequency channels are in some respects superior to any wire circuit. For telephony we may have in them a perfectly silent line, and one with no distortion whatever. The attenuation is greater, but it is not attenuation which limits wire telephony at present, but a mixture of line noises with distortion. With these new channels the telephone repeater comes into its own, since there is nothing to repeat but pure articulation and quality. The telephone receiver itself may be of the radio type, 10 or 15 times more sensitive than those possible to use in wire telephony. In printing telegraphy these channels should also be useful as they can operate relays. They are free from many fluctuations of pure radio circuits, such as day and night differences, etc., and in a twisted-pair become very reliable indeed. The new ionized-gas form of generator now furnishes a convenient high-frequency source in single or multiple units. The power required is negligible when compared with the case of free waves in three dimensions. The object of these remarks, therefore, is to offer a plea for a more general survey of telegraphy by engineers and physicists at this stage of rapid progress. At present we find the separation and segregation of the field of telegraphy into certain more or less watertight compartments under the head of wireless telegraphy, land-line telegraphy, ocean-cable telegraphy, etc., each of these possessing a separate technique. For instance, the radio engineer prefers to think in wave-lengths, and he calls a variable inductance a "variometer" and a certain tuning coil a "jigger," etc., whereas, of course, there is nothing new in principle in these pieces of apparatus. The wire engineer prefers to think in terms of "frequency," and plots his graphs with  $n$  as a principal variable. The cable engineer thinks in terms of "curves of arrival." Has not the time arrived for the standing telegraph committees, wireless committees, cable committees, etc., of our scientific societies to combine in a membership that can look at this whole subject as one subject, which in fact it appears to be?

Mr. W. JUDD: The author mentions the question of printing telegraphs on long ocean cables. The whole of the Eastern Company's cables that land in England are fitted with printing telegraphs and work into London direct; all the traffic is received and printed off ready for delivery. We have one circuit working direct between Alexandria and London; we have two working between Gibraltar and London; we have one working between Lisbon and London; and we have two working between St. Vincent, Cape Verde Islands, and London. All those six cables bring the traffic direct into

the City where it is printed off ready for delivery. We are using both the Morse code and the ordinary cable code, and we are trying to find out which is the better. Up to the present time we have not been able to decide. The speed and the amount of traffic which can be carried are just about the same by either method. We are using in London the Creed system with one or two of the cables, and we are using perforators of our own on the others, largely due to my friend Mr. Fraser, who designed them. With regard to the question of alphabets, we had brought to us in 1901 by Mr. Donald Murray a 3-unit alphabet which is very ingenious; it works out at about 33 units per letter, taking the word spaces into consideration. The advantage in the matter of speed, therefore, in changing from our present system, which is the universal conventional alphabet, to the new one, would be very small; it would not justify any change. Supposing, however, the gain anticipated were considerable, both the 5-unit and the 3-unit alphabets are unreadable at the distant end of a long cable, and the question of being able to read the signal that is coming in to operate the printing mechanism is of absolute importance to us; we cannot do without it. On land lines one can be fairly certain that whatever is put in at the sending end of the line will be received in identical form at the other end of the line, but on a long ocean cable there are deformations, distortions, disturbances, etc., and with all the delicate cable relays and apparatus of that kind we must have people on the watch looking at the record as it comes in and diagnosing any deviations from the normal, so that they may be rectified before they cause a breakdown. The question of the "readability" of these signals is a *sine qua non* with us. It is a thing that does not occur in land-line telegraphy. We shall continue to extend the use of the receiving perforators, as we call them, and of the printers all over the service if we can only get time. We are extending it now, and should have got a great deal further if it had not been for the war, which has delayed the delivery of apparatus.

Mr. DONALD MURRAY: This paper is of special interest to me because I have frequently urged upon the author the importance of publishing more freely the results of his research work in connection with the development of printing telegraphy. The paper seems to me to outline the possibilities in connection with printing telegraphy; that is to say, it shows in a general way the limitations within which printing-telegraph inventors must work and the means at their disposal. There are books showing all the known mechanical movements, and this paper gives in a generalized form practically all the known movements of printing telegraphy. It is a compendium of the stock-in-trade of the printing-telegraph inventor, and with the author's paper before him any competent engineer can now design a printing telegraph. The inventive stage is nearly over. The mystery is gone and printing telegraphy has become one of the exact arts. There is only one portion of the subject left for some future paper, and that is the means and methods and mechanisms that will be employed for linking up the individual circuits of the great printing-telegraph networks that are spreading all over civilized countries. The author has made some brief reference to this subject at the end of his paper; but there is a great deal more to be said and done and invented

Mr. Judd.

Mr. Murray.

Judd.

before a comprehensive paper on printing-telegraph networks can be written. Some idea of what such networks will be like may be obtained by inspection of Figs. 8 and 9 in Mr. Beard's recent paper<sup>26</sup> on "The Design of High-pressure Distribution Systems." It is curious to note how many of the devices described by the author date back further than is generally supposed. Taking one or two such items, I was assured by an inventor of a keyboard perforator that the selecting device shown at E in Fig. 21 was "new in the art." The author, however, finds that it was used before in type-composing machines. Printing-telegraph translators are quite remarkable in this respect of dating back, and the lion's share of credit in this department seems to be due to Baudot. Many inventors have availed themselves of the permutation bars shown in Fig. 25. They have been and remain a favourite device with me, but I did not know that Baudot had employed them. Also I did not know that Baudot had tried the

signals themselves. Quite independently of me the Siemens automatic system adopted the same plan at a later date, and Picard developed the idea in a very ingenious way, adding the improved arrangement shown in Fig. 83. Picard's plan is strangely like the device subsequently invented by Rainey, shown in Fig. 85, and Picard's device was probably the inspiration also for Fig. 84. Picard's rectification arrangement shown in Fig. 86 bears curious analogies to the subsequently developed plan shown in Fig. 87. These Picard inventions are the more interesting because in British patent 9666/1914 by Dixon of the Western Electric Company, the first claim is for a system of synchronism in which the polarity of the current in the line is changed at the distributor during the rotation of the latter, irrespective of whether signals are being sent or not. That is exactly what the Picard system has been doing for years. It is true that the claim refers to the "speed" of the distributor being corrected. If the claim

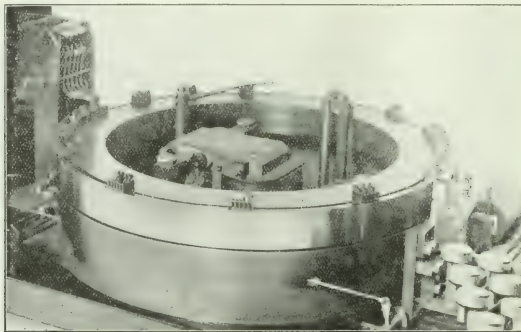


Fig. A.—Ring transmitter.

permutation-disc plan shown in Fig. 26; and the similar device illustrated in Fig. 28 is identical in all essential respects with the arrangement employed by the Western Electric Company. The early electrical translator of Baudot (Fig. 24) is also of special interest in view of its recent use in the Siemens automatic system. The illustration of the Kirk Himrod overlap device in Fig. 64, likewise since adopted in the Siemens automatic system, reminds me that I saw the Himrod printing telegraph in New York about 15 years ago. It was beautifully made, and it had a transmitter that stored up three or four letters, thus giving a certain degree of freedom of the keyboard, but it used positive, negative, and zero units for signalling, and that was fatal. Printing-telegraph inventors know better now. Another example of how great minds think alike is to be found in the device for correction of synchronism from the signals themselves. I suggested in 1903 the use of the idle signal for a multiplex system synchronizing from

is interpreted in this narrow sense as being confined to distributors with speed correction, it may pass, because Picard uses the superior method of clock-hand correction, and this does not entail speed correction; but a broad interpretation of the claim is certainly not justified by the state of the art as explained in the author's paper. The Picard arrangement is free to all to use, and cannot be monopolized by any subsequent inventor. Another subject of special interest to me is the question of metal-pin storage transmitters, which the author has illustrated in a generalized form in Fig. 17. I did a good deal of experimenting along this particular line for the British Post Office, and members may be interested in the photograph reproduced in Fig. A, which shows what I described as the "ring transmitter" made for the British Post Office about nine years ago. The author's description will enable it to be understood. There is a rotating ring driven by a small motor in the centre. On the periphery of the rotating ring are small sliding letter blocks, in which

<sup>26</sup> See pp. 134 and 136.

I used small levers or "leaves" capable of being set in one of two positions. Setting of the leaves in the letter blocks takes place by means of the keyboard on the right, and the transmitting mechanism is on the left. One great drawback to these metal-pin transmitters is that although they are cadence-free they are not speed-free. The keys can be struck freely but not rapidly, nothing like so rapidly as in keyboard tape-perforators. My experience is that they are not suitable for busy multiplex circuits, and my impression is that there is a good field for them on minor circuits where the pressure of traffic is not so great as to demand rapid operation on the keyboard. Such machines have the curious capacity of acting as what I may describe as "channel repeaters." They can retransmit from any one channel of a multiplex circuit into any other channel of another multiplex circuit. This facility may prove valuable in future years. They can also be arranged to retransmit Morse cable signals at ocean-cable stations in such a way that perfect signals are retransmitted from imperfect signals. One of the disheartening features about printing telegraphs is the extreme slowness in getting such apparatus established in commercial use. Perhaps the most remarkable instance of this inertia is the neglect for long years to employ the phonic wheel motor and vibrator to drive the Baudot distributor and printers. All the arguments are in favour of this arrangement, but it has lain neglected for more than 20 years. At last, however, thanks to my employment and persistent recommendation of them, the phonic wheel and vibrator are coming into their own for multiplex work. Another curious illustration of the difficulties with which printing-telegraph inventors have to contend is supplied by the history of automatically alternating transmission of messages. I suggested this arrangement in a confidential paper in 1903, and Mr. John Gell also hit upon the same idea independently of me, patented it, and applied it to Wheatstone working. Mr. Gell has been working for several years to get it into use, but up to the present it has not secured a permanent footing. I have arranged terms with Mr. Gell under his patents for using it with the Murray multiplex, and I have repeatedly urged its value during the past two years, but so far with little effect. It enables each of two typists to transmit, say, 60 messages an hour to one printer, printing, say, 120 messages an hour, thereby raising the operator average from 60 to 80 messages an hour. It is unquestionably valuable, and I have no doubt be used after Mr. Gell and I have passed on to the inventor's heaven where all inventions are adopted at once and huge royalties are paid to the inventors.

MR. E. RAYMOND-BARKER: In submitting this paper the author has given submarine-cable authorities and their engineers a lead which I venture to hope they will see their way to follow, once the present war tension is at an end. The present-day electrical departments of the leading cable companies team with interesting data and new departures and could provide first-rate material for an occasional telegraph paper. With regard to Fig. 13, may I suggest that the author would make his comparison all the more complete were he to add a graph of what is generally known as the "cable code." He will find that, taking the word "London" as he has done, the cable code, with equal-time-value dots and dashes, will give him 49 units as com-

pared with 69 on Morse.\* Apart from the future of 5-unit code telegraphy on high KR cables—a matter regarding which I seek information—apart, also, from the special information we have heard this evening from Mr. Judd, it is probable that, on the majority of high KR lines, cable code will hold its own against any form of Morse, excepting, perhaps, Morse worked on Picard's perfectly self-neutralizing system of inverse-current momentary impulses. It is clear, too, that Picard transmission may be applied to cable-code purposes. The late Mr. John Gott's 2-power inverse-current system of transmission, also Colonel Squier's sine-wave alternating-current system, using three amplitudes, are both based on the cable code. As regards type-printing telegraphs on high KR cables, as far back as 1898 Picard, whose Baudot work on the French Government Mediterranean cables has been mentioned by the author, made the following claims for his momentary-impulse inverse-current transmission, which I will read from his specification:† "Even the Baudot instrument, at a reduced speed compatible with the length of the cable, could be used between, say, Paris and New York, with relays at the land ends. . . . In these conditions the efficiency of the Baudot . . . will certainly not be less

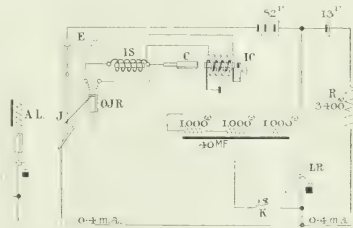


FIG. 13.

than that of the siphon-recorder." On page 362 the author very pertinently refers to a certain working speed as being too high if the maintenance cost is to be kept down to a certain figure. This is a point only too frequently ignored by the non-technical, would-be reformer. The author emphasizes another just contention when, on page 363, he recommends moderate-speed direct printing on several Baudot sets over one cable, as shown in Fig. 105. This method of working he compares favourably with that involving the use of some high-speed system with all traffic confined to one set of instruments. In a word, the author shows that, for practical traffic facilities, several low-speed sets on a given telegraph line are more useful than one high-speed set. I am very glad that Heurtley's magnifier and Orling's jet relay and magnifier have been mentioned in the paper, as most remarkable results have been obtained in this direction. On page 363

\* In this same example the use of the cable code with Colonel Squier's unbroken alternations would give a graph total of 24 units. This low figure is due to the space economy inherent to Colonel Squier's transmission in which there is no space waste between contact units, but only to the extent of one space unit between letters, and two units between words.

† British Patent, No. 2382 1898.

Mr.  
Cayton &  
Barker.

the author refers to a certain drawback as impeding the usefulness of magnifiers, namely, the unwelcome magnification of disturbances. I have been able this evening to confide to the author particulars of a simple device originated and patented\* by Mr. Orling, thanks to the kindness of the latter. This device prevents any abrupt disturbances that may be agitating the multiplier from affecting the local siphon-recorder, which, however, itself remains free to record incoming cable signals. The author, also, has records of signals which show in a most remarkable manner the efficacy of Mr. Orling's device.

(Communicated) The smaller diagram in Fig. B shows the essential feature of one of the alternative schemes for eliminating abrupt electro-vibratory disturbances from cable siphon-recorder signals, namely, an adjustable inductive resistance or small block of artificial line (A L) in series with a local recorder, with the inductive surface connected shunt-wise. A similar device applied to a siphon-recorder worked direct from a cable will be found to be non-effective. The larger diagram (Fig. B) shows the conditions of a drastic test devised to prove the

receiving condenser of 7 mfd. The periods of "off" and "on" controlled by the experimenter with key K are clearly shown, and the beneficial effect of the device is seen to be most marked. To determine whether an increase of speed would cause the cable signals to become affected by the damping device, the rate of transmission was raised to 260 letters per minute, as shown in the lower record in Fig. C. Here are the words: "The quick brown fox jumps..." with the corrected signals perfectly formed, and those non-corrected quite illegible. In this connection it is well to remember that jet-magnifier signals obtained over actual Atlantic cables are better than those recorded through the roughly-made-up equivalent artificial KR of 4 here mentioned.

Mr.  
Barker.

Major A. C. BOOTH: I should like to call attention to Fig. 13, which shows the Hughes as the most inefficient of the instruments mentioned, even one point worse than the step-by-step instruments. This may lead to misapprehension of its capabilities, which are so great that they have justified its use for more than 40 years, and which have

Major  
Booth.

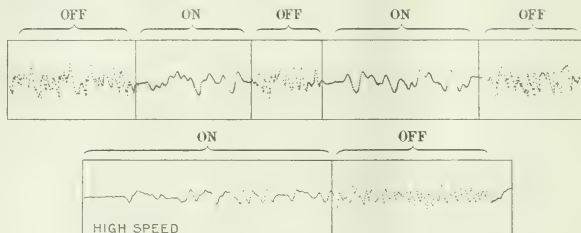


FIG. C.—Orling Correction.

efficacy of the correcting device when applied to a local recorder (L R) controlled by an Orling jet relay or magnifier (O J R) used as receiver on an artificial cable (C). With key K left up, the correcting device is "on"; with the key down, the device is "off." For the purposes of the test, an ordinary Ruhmkorff induction coil (I C) and a local battery were joined up to O J R and the inductive shunt (I S) for direct reception from C. Simultaneously with the reception of signals sent into the distant end of the cable by an automatic transmitter, the continuous vibration of the armature I C caused the cable signals on the jet to be broken up by the rapid and abrupt electric disturbances produced. As long, however, as the correcting device was applied to O J R by key K being left up, all cable signals continued without interruption to be satisfactorily recorded on L R, all ill effects arising from the abrupt disturbances ever visible on the jet having been damped down and eliminated; whereas with the device "off" the cable signals were obliterated by the disturbances. The upper record in Fig. C shows the words "jumped over the lazy dog" received from a sending-battery of 3 volts at 160 letters per minute over a KR of 4 with a

given such satisfactory results that some 3,000 instruments are in use in Europe. It may occasion some surprise to many people that although only giving an output speed of about 30 words per minute it actually prints at a speed greater than 120 words per minute; that is to say, it will print clearly a string of separate letters at a speed above 120 words per minute. I have seen it working at 164 words per minute, which is not much below the speeds of our latest and most improved machine telegraphs. I think this paper would not be complete without some reference to the good work done by the Post Office in the development of machine telegraphs. In 1892 or thereabouts John Chapman of the Post Office duplexed the Hughes apparatus and thereby extended its use. In 1899 Sir William Slingo considerably extended the use of the Hughes duplex on telegraph cables to the Continent. In 1897 the Baudot simplex was installed on a circuit to France. In 1902 the Murray automatic commenced its career. In 1905 the duplexing of the Baudot was suggested, but for want of apparatus a working circuit was not equipped until 1910. In 1909 the Murray multiple simplex was first put to a working circuit. In 1911 the Murray multiple duplex was installed. In 1914 the Western Elec-

\* British Patent, No. 17925-1914.

tric multiple duplex was put to work in this country. For some 40 years the Hughes and Baudot held the field in printing telegraphs for telegraph administrations, and with the exception of the excellent Creed apparatus all the successful present-day printing telegraphs, and this includes the Siemens automatic, are developments of the Baudot. This at once raises the question as to why the Baudot remained quiescent all those years and has only recently become subject to this sudden great liveliness all over the world. The answer is plain and incontrovertible—it is solely because it has been duplexed, whereby its output has been doubled, as referred to by the author on page 362, giving 8, 10, and 12 channels where only 4 and 6 previously existed. It is not for the Post Office, being practically a trustee of public funds, to expend large sums of money in the inventor's province; but the Post Office encourages inventors to develop their ideas; it gives them freely the benefit of its wide experience and assists them as far as is practicable to perfect their machines to meet the requirements it knows so well. I remember the arrival of Mr. Murray's hand-driven machine and how under the guidance of Mr. Eden and Mr. Hatfield, both of the Post Office, he was led to develop it to the very efficient condition of the last few years of its life in the Post Office; but still it did not meet requirements and had to be turned down. Now that he has accepted the suggestions made to him by the Post Office there is much more likelihood of his multiple duplex proving satisfactory. I am sure Mr. Creed and Mr. Gell will be only too willing to acknowledge the great help they have received from the Post Office in the development of their particular machines. There are many other inventors I could name, not only in connection with telegraphs but also with telephones, wireless apparatus, batteries, etc., who are all more or less indebted to the Post Office for material assistance. The author may be interested to know that besides the sextuple duplex, the quintuple duplex, and the quadruple duplex Baudot circuits which are working on inland lines in England, there were triple and double duplex Baudots from this country to Germany; and triple duplex to Belgium. The provision of triple duplex Baudot to Holland was agreed to, but was postponed on the outbreak of war, and there are now triple and double duplex Baudot circuits from this country to France. I believe also the Baudot double duplex is now in use in India. Regarding the author's conclusions, I must join issue with him on the first paragraph, as there were no "mists of doubt" so far as the Post Office were concerned. Finally I cannot agree that the everyday typewriter can compete successfully in long life against the type-wheel, even at 50 words per minute, when it is required to work day after day from 8 a.m. to 8 p.m. and perhaps all night too. Both Creed and Murray have had to construct specially-stout typewriter mechanism for their machines.

Mr. J. J. TYRRELL: I should like to remind Major Booth that he did not give any credit to the Russians, who preceded the British in the adoption of the Baudot duplex. I notice that Major Booth shakes his head, and I accept his correction. Still, the Russians have adopted the Baudot and have worked it duplex. The fact that the Belgians took so well to the Baudot duplex is also worthy of record. It may be of interest if I state that the London-Antwerp Baudot duplex held on to the very last minute when the wires worked between this country and Antwerp,

even when we could not get through on Morse and when the line was diverted through quite a circuitous route and was thus made up of various and variable sections. We were able to use the system even when the enemy were endeavouring to tap it, and we got some of the most important work through at the eleventh hour, just before the fall of Antwerp. For myself, I shall never forget the sadness of breaking off the last connection with the Baudot triple duplex between London and Antwerp. The marvellous part of it was that the insulation of the Belgian sections of the wire was so bad that we had to repeat nearly everything three or four times before we could get it through; nevertheless the system held up and at last we succeeded in finishing the dispatch. The great feature of the whole thing was that we were able to get it through without the information being tapped by the enemy, although we knew very well that he was doing everything he could either to upset our synchronism or to obtain information. There is one point on which I should like, if I may be so bold, to correct Sir William Slingo. He seemed to think that 20 years ago people looked askance at a printed telegram. Thirty years ago, to my personal knowledge, some thousands of printed telegrams per day were being issued from Throgmorton-avenue office, then in the hands of the late Submarine Telegraph Company. Those messages were all printed by the Hughes telegraph apparatus, and they were by no means looked at askance by some of the most practical men in the City of London, namely, stockbrokers, shippers, and merchants.

Mr. W. L. PREECE (*communicated*): Although this paper is most exhaustive, the author has had to limit his subject to descriptive comparisons of the various inventions of printing telegraph apparatus, and has not been able to refer to the equally important comparison of the monetary value of any particular form on any special circuit. There are in use now two types of printing telegraph apparatus, the multiplex, of which the Baudot is the chief representative, and the high speed, of which the Creed is best known. To any administrative engineer the main point to be considered is: which of these two types is the most suitable for the particular circuit he has in view? The decision rests on the following factors:—(1) Quantity of traffic to be handled; (2) capital outlay; (3) maintenance; (4) staff required. Let us assume as illustrations a circuit between two important centres over which it is required (a) to transmit a maximum of 100 words per minute in each direction, (b) 50 words in each direction. In regard to (a), the decision rests between Baudot 4-arm duplex which can handle a maximum of 240 words per minute, and Creed duplex which can handle certainly 200 words per minute. The Baudot costs approximately £1,000, the Creed £2,000. The maintenance of both is fairly equal. As regards the staff, however, the Baudot requires at each station one attendant, four operators, and four receiving clerks per shift; whilst the Creed requires one attendant, two typist-operators for perforating, and possibly two receiving clerks per station per shift. Thus, whilst the Baudot circuit calls for a staff of 18, the Creed only requires 10. A gain of eight operators per shift, which alone represents a saving per annum of a sum equal to the additional capital outlay. Now assume a traffic having a maximum of 50 words per minute in each direction. This could be handled by a double duplex Baudot, or it

Mr. Preece.

could be served by a Wheatstone set which included keyboard perforators and typewriters for transcribing. The staffs in these two cases per shift would be:—For the Baudot, two operators and two receiving clerks at each station, *i.e.* eight men; for the Wheatstone, three operators at each station, one for the perforator which is known to be able to perforate at the rate of over 70 words per minute, and say two typists, each of whom could certainly transcribe at the rate of 25 words per minute, probably a good deal more. Thus there would be a saving in staff of at least two per circuit in favour of the Wheatstone, which apparatus also requires less maintenance and is simpler and less expensive. One attendant per set would be required in each case. It would thus seem that, for circuits connecting two centres, the multiplex cannot compete with the Wheatstone, if the latter is coupled with mechanical labour-saving apparatus. Where, however, circuits branch off the main line to other places, and carry a moderate amount of traffic, the multiplex may possibly have the advantage. Major Booth stated that London and Birmingham are connected by two duplex sextuple Baudot circuits. These circuits would therefore carry a maximum of 360 words in each direction, *i.e.* 720 words per minute in all. The staff required would probably be two attendants, 12 operators, and 12 gummers in each station, or a total of 52 persons. Now if the Creed-Wheatstone were employed, and duplexed, at least 800 words per minute could be transmitted over the two circuits, using four receivers, as a maximum, and the staff, for 720 words maximum, would consist of not more than four attendants, 8 keyboard operators, and say 8 gummers per station, or a total of 40 persons as against 52, that is to say a saving of 12 persons per shift in favour of the Wheatstone. Another point which has considerable influence on colonial engineers in favouring the Wheatstone apparatus is due to the fact that the distances in the Dominions between main centres are usually great, and a breakdown of the line may necessitate a long delay. Now if multiplex is used, the messages are received and stored up until the line is again through. Then the transmission must progress at the normal speed, and the time lost cannot be regained. If, however, the Wheatstone is used, these messages during the wait are all perforated on tape. Then, immediately the line is repaired, the whole batch of messages can be transmitted at the highest possible speed to their destination. Also, as all the perforating has been done, the whole staff can be employed in transcribing the messages as they arrive, and often an appreciable portion of the time lost by the breakdown is actually saved in the delivery of the messages.

Mr. Gell.

Mr. J. GELL (*communicated*): In the discussion, reference has been made to an automatic switch that I have invented. By means of this apparatus a number of operators may be engaged perforating slip for high-speed transmission, and each in turn is given possession of the line whilst one message is sent forward. The switching system is so controlled that extra long messages, or unequal abilities amongst the operators, do not detrimentally affect the traffic. The control is so flexible that the number of operators engaged is in keeping with the volume of traffic for the time being. The system enables the usual operator in charge of the transmitter to be dispensed with; the line time is saved by the elimination of the blank slip at the

commencement and ending of batches; each message is sent independently and is not held up whilst the others are being perforated. The time of the perforating operator is saved, because there is no necessity to start and terminate each batch of messages, or to snake up the tape, etc., and send it to the transmitter clerk. In connection with this switch I think it only right to mention the assistance that was rendered to me by the British telegraph authorities. Engineers were sent from London to Glasgow and Liverpool to supervise the installation and testing of the switches. They took as much interest in the success of the switch as though it were their own, and the consideration they manifested towards me is typical of the courtesies I have received from the different sections of the department. Through the knowledge I obtained at this test I was enabled to perfect the switch and make it absolutely reliable. It is considered that this switch will be of value in connection with modern printing-telegraph systems. With reference to printing-telegraph systems generally, I am of the opinion that one uniform type of apparatus will not be adopted, even in any one country. The conditions of traffic vary so greatly on different circuits that whilst it will pay to put a relatively expensive high-speed system between two large cities, on the other hand the traffic on another circuit will only justify a small outlay. The main object to be aimed at is to reduce as far as possible the number of different kinds of instruments, and endeavour to utilize those which for high-speed and low-speed circuits can be handled by similarly trained operators, so as to ensure as far as possible full flexibility in regulating the staff to the traffic.

Mr. F. G. CREED (*communicated*): I shall confine my remarks to the author's conclusions in the last two pages of the paper. He says the last few years have seen the triumphant advance of the 5-unit equal-letter alphabet. In this I think he is mistaken. As Sir William Slingo has already pointed out, the advance made in connection with the 5-unit alphabet has been rather in the nature of refinement in methods and apparatus than in the general introduction of apparatus based on that alphabet. In fact, when one considers how well established the 5-unit apparatus was five years ago, it is rather remarkable that the use of such apparatus has not been much more widely extended in the succeeding period, during which it has been very persistently pressed upon the attention of the telegraph world. The increased use of the 5-unit apparatus in Great Britain, for instance, during the last five years has been trifling, and cannot compare with that made in the last two years by printing telegraphs based on the Morse code. Very much more traffic is handled to-day in the United Kingdom by Morse code printers than by all the 5-unit telegraphs together. The author fears that the use of the Morse code for high-capacity printing telegraphs involves delicately constructed machines at both ends of the line, and all the complexity imposed by the necessity for differential feed devices. This, he thinks, involves high first cost, and, though no information is available, the maintenance must be heavy also. On this point I am able to give some first-hand information. The extra first cost due to the differential feed in the Morse code printer, with which I am familiar, does not exceed 5 per cent per printer, and when made in bulk would not perhaps exceed 2½ per cent. The cost of maintenance, includ-

ing the attendance of a mechanic, does not amount to 5 per cent per annum. The author says that the maximum speed would not be more than about 150 words per minute. As to maximum possible speed, I may mention that a line-speed of 165 to 170 words per minute has been maintained as the normal working speed of the Morse-code printing system used by the *Glasgow Herald* between its Fleet-street offices and Glasgow (400 miles) since the installation of the apparatus two years ago. Although handling up to 80,000 words per night, they have never, as far as I am aware, suffered any interruption or breakdown of the system, and this fact will perhaps be the best assurance that the author's fears about the delicacy and complexity of the apparatus are unfounded. The author believes that high-capacity systems with a low speed per printer unit can be of more robust construction than high-speed printers. Although more of them will be required to do the given work, they can be manufactured more cheaply, owing to their simpler and stronger construction. I am not by any means convinced, however, that four low-speed printers can be manufactured or maintained as cheaply as one fast one. Moreover, the 5-unit system requires not only the printers but the expensive and delicate distributor and control mechanism. In this connection also we must not fail to take into account the difficulty and expense of handling the 5-unit alphabet at repeating stations, a difficulty that is not experienced with Morse printers. Sir William Slingo very justly pointed out that the method of comparing the various codes suggested in Fig. 13 is quite erroneous. An alphabet is faster or slower, not because its unit is smaller or greater with relation to its average letter than the unit of another alphabet, but because it can be telegraphed more quickly or more slowly by means of the instruments in connection with which it is used. Mr. Judd, in discussing the author's suggestions with regard to the application of the 5-unit alphabet to ocean cables, mentioned that in the experience of the Eastern Telegraph Company the land-line Morse and the cable-Morse alphabets can be telegraphed over ocean cables at practically the same speeds, although theoretically the cable alphabet is about one-third shorter than the land-line Morse. In stating this fact, Mr. Judd very neatly exposed the underlying fallacy of the favourite argument employed by the advocates of the 5-unit alphabet. The fact is that at the root of all the controversy between the advocates of the 5-unit alphabet and the Morse lies the failure to recognize certain essential factors which do not appear upon the surface. There are several very good and sound reasons why the 5-unit alphabet does not and never can equal the Morse for printing telegraphs. With some of these reasons I made myself acquainted years ago when I decided to give my allegiance to the Morse. I hope to explain them fully in a paper at some future time. Meanwhile I will content myself with pointing out that, in spite of all the arguments which go to prove that the contrary should happen, the Morse code printer in this country has obtained better results than the 5-unit code in every case where it has been permitted to compete with it on equal terms. By way of indicating some of the difficulties which have still to be overcome with the 5-unit system, may I suggest a few questions arising out of the actual working of the various systems in the United Kingdom?

(1) Why is the Baudot sextuple duplex confined to the short and easy underground loop between London and Birmingham? Mr. Creed.

(2) Why is the Western Union multiplex, with its apparently enormous capacity for work, installed between Manchester and London instead of upon the much heavier London-Glasgow circuits?

(3) Why are all the 5-unit printing telegraphs confined exclusively to underground loops instead of overhead wires, although the Morse printer is used on overhead or underground wires, long or short, with perfect indifference?

(4) Why are all 5-unit machines shut down at night, and why is the Morse code printer the only one that is opened at night to cope with any unusual pressure of traffic or to distribute news?

(5) Why are Morse wires, apparatus, and staff usually kept in reserve in connection with circuits worked by the 5-unit systems?

(6) Why does it take so long, sometimes several hours, to change 5-unit systems, especially when duplexed, from one line to another in case of interruption?

(7) Why are no news circuits in this country worked by 5-unit apparatus?

(8) Why have the majority of the provincial newspapers using private wires adopted the Morse code printer for their work instead of one of the 5-unit systems, which are claimed to be less costly and which have been much longer in the field?

(9) Why does the Western Union Telegraph Company employ a Morse code printer on its most difficult and valuable land circuit (between its New York office and the cable ends in Nova Scotia)? This Company claims to have developed the best of all the 5-unit systems and to have had it in daily use for about two years.

These are questions that call for an answer, and they will find their answer in the hidden and neglected factors to which I have alluded.

The PRESIDENT: Before asking the meeting to give a vote of thanks to the author, I should like to say a few words. This paper, containing two illustrations per page, is one of the most exhaustive that we have ever published. In a time of war, when we have to be economical, we must of course only publish papers of the highest merit, and we decided, at considerable expense, to print this paper. I do not think we have ever received one better put together or more beautifully illustrated. The President.

Mr. H. H. HARRISON (*in reply*): The preparation of the paper has been very largely a labour of love, and carried with it, therefore, its own reward. The appreciation it has met with to-night is, however, none the less welcome. Mr. Harrison.

Sir William Slingo asks why I did not refer to the photographic printer. Type printers employing photographic means for recording have been proposed from time to time, and Adler replaced the siphon recorder on the Mediterranean cables by a photographic recorder of the Einthoven string-galvanometer type, but as far as I am aware all such apparatus has long since disappeared. The developing, fixing, and drying plants incidental to photographic printers take up space, and the extra processes involved must, I think, be regarded as objectionable. The idea of photographically recording signals is very attrac-

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tive; the recording means have no mass and are therefore capable of operation at high speeds, and this is well shown by the performances of the Siemens photo printer which, in spite of its alphabet, established a record. No doubt the reasons advanced against this class of printer explain why the Siemens has ceased to be used even in the country of its birth, but the alphabet was also a contributory cause of its abandonment. The excellence of the Creed apparatus is admitted, but to keep the paper within reasonable bounds it has been necessary to refrain from describing "systems." The Siemens automatic is a high-speed 1-channel Baudot, and as printing is effected directly without loss of line time, Kirk Himrod's overlap has had to be adopted. The one novelty of the Siemens automatic appears to me to be the technically beautiful method of printing. I do not think that my references to this feature (page 356) can be said to be other than appreciative and generous. With regard to the criticism of Fig. 13, the legend was perhaps a little too rigid and I will add to it the words "for the word 'London.'" It is, of course, a time comparison of one word only in the various codes. There is, with this explanation perhaps, nothing misleading about it, as the ratio of 8 to 5 for Morse and 5-unit code is generally accepted. I agree that the automatic stop and start can be dispensed with, in fact I say so in the paper. By its omission the attention of the perforating operator is divided and concentration on the work of perforation is not so complete as when this device is added. Without it, manual stop and start must be arranged for, and a certain amount of tape has to be perforated before transmission can be commenced. The operator must watch the tape to see that transmission is not overtaking perforation, and the mental strain, slight though it may be, re-acts on the operator's efficiency. An alternative to this is to punch each message complete and then run it through the transmitter. Either method leads to slower handling of traffic, and it is worthy of note that the record traffic figures for a multiplex circuit (the Boston-New York circuit of the Western Union Company) have been attained on apparatus fitted with automatic stop and start of transmitters. In the original automatic stop-and-start device described in the paper the few extra parts are attached to the transmitter itself and no separate piece of apparatus is involved. The objections to any considerable flywheel capacity for distributors seem to me to have been set out at sufficient length in the paper. Fig. 97 is not, of course, the only way of providing for automatic 2-way repetition on long lines, but where channels are forked at the repeating station, or if re-transmitters are used, it is found to be useful. For a direct A to C communication with B as a repeating station, the ordinary Wheatstone type of repeater may be used, as Sir William Slingo points out. I prefer to adhere to my statement that the 5-unit alphabet has triumphantly advanced during the last few years. The discussion has shown that the 5-unit alphabet is believed to be inapplicable to long cables, and not that printing telegraphs cannot be used. Moreover, the alphabet used is one of the fundamentals of any printing-telegraph system; and the increasing adoption of printing telegraphs is due, amongst other things, to recognition of the advantages of an equal-letter alphabet of which the shortest practicable as well as one of the oldest is the

5-unit. The change from a defective alphabet to the 5-unit code has been sufficient to convert a system which has languished for years as a commercial failure into one with a hopeful future. The Cardwell is an instance of this. Morse operators will always be in demand for the purposes outlined by Sir William Slingo. Whether or no the printing telegraph will replace the high-speed Wheatstone at field telegraph offices in the wars of the future, I should not like to venture a prophecy, but it may be noted as an interesting novelty that the French have a portable Baudot in the field. The figure of 130 to 150 words per minute which I have given relates to type-bar printers. For the Siemens automatic I have given the same figure as that quoted by Sir William Slingo, viz. 1,000 letters per minute (page 356). I am glad to note that Sir William considers 130 to 150 words per minute a liberal figure for automatic systems not employing the 5-unit code, as these figures have been questioned. A 1-channel manually-operated printing telegraph could be worked between London and New York to-morrow if it were considered advisable to do this. I had the privilege some time ago of witnessing direct communication between London and New York with two Hurtle amplifiers in circuit, land-line Morse being used and commercial traffic passing. Taking the generally accepted speed constant of 750 for duplex working with amplifiers, then, for a cable of  $KR=4$ , 187.5 in cable Morse, or 135 letters per minute in the 5-unit code, are possible. This is not brilliant and, perhaps, hardly worth doing, but if a continuously loaded cable were laid and Colonel Squier's sine-wave transmission adopted, the combination would be rich in possibilities. It is interesting to hear of the new form of relay developed by the Post Office engineers. The Western Union Company are using on their multiplex circuits a modified Guldstrand relay due to W. Finn, and in a recent paper before a Convention of Railway Superintendents in America Mr. J. Hume Bell (formerly of the Engineering Department of the British Post Office) described a simplified Guldstrand relay which appears to work very satisfactorily. All these are based on Guldstrand's work, and as he gave his results freely to the world I hope that his name will be perpetuated in some suitable manner. I do not think that equated figures from Wheatstone results are quite satisfactory. On long lines and near the transmission limit the adjustment of the receiving apparatus is a compromise due to the conflicting influences of the two lengths of signalling elements in the Morse code. As the speed is raised the dots tend to become mere pin points. If they are thickened up by giving the receiver a "marking" bias, the dashes tend to run together. The adjustment for the Baudot has no such opposing requirements, and that this is so is sufficiently shown by an article by C. T. Williams\* in which it is stated that in India under bad line conditions a double Baudot gives a better output than the same circuit worked by Morse. I do not question the fact that correction from the signals is workable. It has worked well in France for some years. Correction from the signals does, however, bring disadvantages in its train, and that is why I say that unless the saving of some 9 per cent of line time is absolutely necessary, the special correcting signals are to be preferred. My reference to the experience of the

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\* "The Baudot Telegraph System in India," *Electrician*, vol. 58, p. 881, 1906-7.

French Administration with synchronous multiplex apparatus was intended to apply to length of time. The French have had the Baudot since 1874, and prior to that the multiple Morse system of Bernard Meyer.

I appreciate to the full the interesting contribution to the discussion furnished by Colonel Squier. It is stimulating, and opens up to view a fairland of research delightful to contemplate. To work a double duplex across the Atlantic using the 5-unit code, we require  $n$  to be 15 for a speed of 30 words per minute per channel. With existing types of amplifier the magnification required cannot be attained, and even if it could it is doubtful whether the cable would then be workable. By adopting two transmitting frequencies and electrical and, possibly, mechanical resonance, a workable scheme might be developed.

The information furnished by Mr. Judd as to the activities of the Eastern Telegraph Company with printing telegraphs on long cables is most interesting. I was certainly not aware that the foremost cable administration in the world had done so much in this direction. I had rather gathered that they were by no means idle in this connection, as from time to time very ingenious specifications appear under the names of Angus Fraser and the Eastern Company. As to the difference, if any, between cable and land line Morse codes, if the transmission capabilities of the cable and the working speed necessary to deal suitably with the volume of traffic are so related that the difference between them is considerable, then, obviously, it is a matter of indifference, so far as transmission is concerned, which code is used. When the required working speed approaches the maximum possible speed of the cable under consideration, then there is no choice and the shorter cable code has perforce to be adopted. Land line Morse would be used on all long cables if practicable, as re-translation into cable code would not be necessary and land line and cable could be interlinked by automatic repeaters. As it is, manual translation is only avoided by receiving perforators which, actuated by perforated tape in the one code, reproduce a fresh tape in the other code (Creed), or by an automatic transmitter which when fed with tape perforated in the land line code sends the signals on in cable code (Fraser, Eastern Telegraph Company). The adoption of cable Morse in its relation to a printing telegraph tends to a reduction in the number of parts, and shorter feeds are necessary as compared with a printer designed to use land line Morse. The objection to the illegibility of the 5-unit code recorded on a tape as received on a long cable is very real, and I do not wish to advocate its use for such cables. My reference to type-printing telegraphy on long cables is more in the nature of a suggestion than a recommendation.

I cannot quite agree with Mr. Murray that the era of design has now set in. There are still a few more things to be settled before this may be said. Our knowledge has advanced and is advancing, but many details are still a matter of design by "eye" and not an exact and predetermined result. Mr. Murray does right to point out that mechanical-storage transmitters are not "speed" but only "cadence-free." Whatever mechanical means of storage be employed, it cannot be operated at a speed approaching that at which holes can be punched in a paper tape. Further, there are no pronounced inertia effects due to the negligible weight of tape concerned in either the

setting or transmitting operations. When a perforator or transmitter are used mechanical storage up to about 12 letters will be valuable between the keyboard and line of 1-channel manually-operated printing systems, and also to act as a retransmitter in the manner suggested by Mr. Murray.

In answer to Mr. Raymond-Barker, Fig. 13 is really superfluous, as the relation 8 : 5 : 3·6 for land-line Morse, 5-unit, and cable Morse codes is generally accepted. Fig. 13 illustrates, however, mechanical features which have to be considered when an equal-letter alphabet is not used. I am interested in Mr. Orling's device for overcoming disturbances on cable circuits equipped with amplifiers. From figures that I have been able to get both from Mr. Raymond-Barker and others, it would appear that all amplifying devices give the following speed constants:—Simplex maximum 1,000; simplex (maximum commercially) 900; duplex 750. These figures divided by the KR of the cable give the possible letters per minute. Duplex working is the only commercially practicable method to consider, and we have as a result that the employment of a modern amplifier will send up the working speed on a long cable 50 per cent.

In answer to Major Booth, Fig. 13 shows, and quite correctly, that if in a certain time the word "London" and a word space is sent on the Hughes it can be sent 3·6 times with the 5-unit code. It is well known, I think, that the Hughes speed is about 30 words per minute, but it is well that it should be put on record here. The Hughes has given yeoman service for over half a century, but I imagine that if a simple 1-channel instrument using the 5-unit code had been brought out 20 years ago the Hughes would have disappeared, in France at all events. It comes as a surprise to me also that the Hughes can be worked at 120 words per minute. From experiences I have had with 1-revolution clutches, I can only say that I should not care to have the maintenance of the Hughes in my hands if worked at that speed as a matter of everyday procedure. Major Booth's references to the good work done by Post Office officers is fitting and just. I have urged this also elsewhere. I am endeavouring, further, to get a list of mechanics who have played a part in the development of the various systems. I know from my own experience how helpful an intelligent and interested mechanic may be, and it is, I think, well known that the present-day 2-disc combiner of the Baudot was due to one of the mechanics connected with the workshops of M. Carpentier. I agree also that the application of the duplex balance has had a profound influence towards increasing the adoption of the multiple printing telegraph. Some two or three years ago I was sent by my Company to France and, by courtesy of the French Administration, enabled to study the Baudot under specially favourable conditions. I never felt satisfied with the reasons given for not applying the duplex principle. I can also entirely agree with Major Booth as to the open-mindedness and helpfulness of Post Office officers, both engineering and traffic. Major Booth misunderstands my conclusion as to the type-bar translator. At 40-50 words per minute it is possible to take existing commercial articles and work them with, I think, reasonable maintenance. Telegraph Administrations are large users of typewriters. They should select the most suitable machine, which would serve the two purposes. The main-

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tenance on any type-wheel translator that depends upon "positioning" the type-wheel is known to be heavy.

Mr. Tyrrell's remarks hardly call for any reply on my part, but I find them very interesting. The question of priority in the application of the duplex balances to multiplex circuits appears to be in doubt. As far as I know, it was first applied to the Delany Morse multiplex in 1896 by Mr. S. A. Pollock. It was first applied to multiplex printing telegraphs by Rowland, while the first to adapt it to the Baudot was Major Booth.

With regard to Mr. Preece's written remarks, he gives the costs of the Baudot and Creed apparatus as approximately £1,000 and £2,000 respectively. This is also very nearly correct if we substitute a modern multiplex with keyboard perforators and automatic stop and start. The modern multiplex working at 50 words per minute per channel will transmit at 100 words per minute with two transmitting operators, two receiving operators, and one dirigeur at each end, i.e. a total of 10 for the whole circuit, a result identical with the figures he gives for the Creed. At 50 words per minute in each direction the modern multiplex would require two operators at each end and could be a simplex-double, the total staff numbering six. Mr. Preece does not say anything about a transmitter clerk, two of whom would be required for the Wheatstone, as he cannot expect 50 words per minute from the perforator operator if he has also to attend to the transmitter. Thus it would appear that for multiplex the staff would be six and for the Wheatstone eight, exactly the reverse of the figures Mr. Preece gives. I have allowed for the whole of the dirigeur's time at each end of the line, but British Post Office practice is to allot two circuits per dirigeur, so that I could make the figures with respect to the multiplex even more favourable. All this does not touch the question of the quicker handling of any corrections on the multiplex as compared with the automatic. A further reduction in the first case, i.e. 100 words per minute, could be effected by receiving on a perforated tape and having one printer and, consequently, one printer attendant only. The staff would then be in the ratio of 8:10 in favour of the multiplex, but the advantage of directness of transmission between sending and receiving operators is sacrificed. In cases of breakdown, my experience has been with the Wheatstone that the total delay is out of all proportion to the time of interruption. Mr. Preece's remarks infer that Wheatstone speeds are incomparably higher than multiplex on long lines. The exact opposite is the case. Here are some interesting figures taken from Mr. Williams' paper referred to above. On a 1,000-mile line 50 messages per hour were dealt with duplex Morse. On the same wire a Baudot double dealt with 120 messages per hour as a maximum and 90-100 easily. Experience in India shows that a double Baudot doubles the capacity of a wire as compared with Morse duplex. On the Petrograd-Omsk line worked duplex with three repeating stations and having a length of 2,200 miles consisting of iron wire, the Wheatstone speeds were 30 words a minute, occasionally 35, and under the very best conditions and for short periods of time 40 words per minute. The speed for a 7-channel 5-unit code system is 56-60 words a minute regularly. Pouring traffic through a Wheatstone transmitter at highest speed only transfers delay from office A to office B. Mr. Preece's assumption

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that a good portion of the perforator operators can be turned on to transcription carries with it the necessity for traffic to cease being handed in at both centres. If the speed of transmission by the Wheatstone is 8 words per minute, then the theoretically possible speed with the 5-unit code is 8S/5, and the actual speed is higher than this, as shown by the Russian and Indian figures. The explanation for this lies in the fact that much less perfect signals will successfully operate a system using the 5-unit code than one employing a Wheatstone apparatus. If we only assume equal speeds for the multiplex and the Wheatstone automatic which is giving something to the latter, then, in the case of Mr. Preece's hypothetical breakdown, the total delay to the traffic approximates to the duration of the stoppage for the multiplex, while the delay due to transcription must be added in the Wheatstone case. I cannot do better than quote the words of an experienced traffic officer on this point. In his paper "The Telegraph Service, Methods and Results" read before the Post Office Telephone and Telegraph Society on the 24th November, 1913, Mr. John Newlands, Controller of the Central Telegraph Office in London, said:—"Experience has shown that delay tends to increase when resort is made to Wheatstone working, but with Baudot the general delay is at once reduced because of the ease and celerity with which the traffic can be disposed of."

Mr. John Gell has explained the advantages of his plan of alternate switching so completely that there is little for me to say. The adoption of Mr. Gell's switch at the transmitting end will cut out some of the time leakage on automatic circuits, and will do for them what the Creed printer has done at the receiving end. In this respect it is of advantage both with pure Wheatstone and Wheatstone-Creed. I fear, however, that owing to the number of high-speed transmitters involved, the first cost of an installation and also the increased cost for maintenance will make it rather expensive. When Creed-Gell refinements are applied to a Wheatstone circuit, we are one step nearer to the ideal method of handling traffic, but there is still lacking the direct and instantaneous connection between transmitting and receiving operator furnished by the multiple system, and delay in obtaining RQ's exists. In connection with the London-Edinburgh traffic in which three line wires were used, two for traffic and the third for obtaining corrections, Mr. Newlands, in the paper before referred to, says:—"It ought to be stated that the double Wheatstone equipment with say three or four Gell perforators, two Creed re-perforators, and two Creed printers . . . is an arrangement which involves an excessively high capital outlay for apparatus far and away above that of other systems. . . ." On the top of this Mr. Gell proposes additional apparatus which still further adds to the capital outlay.

Mr. Creed thinks that the development of apparatus using the equal-letter alphabet has been slight during the last five years. The figures given in the table on the next page are taken from the last statistics issued from Berne. I believe the Post Office have 40 Creed installations, and it is known that 1 Siemens automatic and 1 Western Electric quadruple-duplex are in use. These do not appear on the above list. I have not the previous Berne figures at hand, but the figures, except for France, represent the development in Europe for the last 6 or 7 years.

For the same period the figures for France have practically doubled. The figures for Russia are now higher than those given in the table. In addition to the above the Western Union Company have installed 25 quadruple duplex circuits, are installing 25 more, and are contemplating a further 50. India, Ceylon, Brazil, and the Argentine Republic have installed multiplex apparatus, while New Zealand has ordered equipment and Australia has issued a most comprehensive specification for a printing-telegraph network. Mr. Creed tells me that his equipment has also been supplied to Australia, China, Japan, India, South Africa, Sweden, and 12 of the leading provincial newspapers. Telegraph Administrations have found printing telegraphs using differential feed devices subject to frequent failure. The apparatus is costly to maintain and the first cost compared with apparatus of greater capacity is nearly twice as great. The figure of

	Creed	Equal-letter Systems
Austria ... ..	—	8 Baudot
Denmark ... ..	7	—
France ... ..	—	1,155 channels. Baudot
Germany ... ..	—	30 Baudot
		1 Murray
		16 Siemens
United Kingdom ...	—	22 Baudot
		59 Baudot double
Italy... ..	—	93 Quadruple
		4 Rowland (quad- ruple duplex)
Norway ... ..	—	2 Murray
Russia ... ..	—	115 Baudot
		3 Murray
Spain ... ..	—	10 Baudot
Switzerland ... ..	—	8 Baudot
France (Algeria) ...	—	34 Baudot

5 per cent for maintenance tells us nothing as we are not given the total sum on which it is based. With reference to the working speeds of Morse code printers, in an article in the *Post Office Electrical Engineers' Journal* for October, 1913, Mr. E. Lack says:—"The printer has been experimentally worked at a speed of 128 words per minute, but 100 words per minute is generally regarded as the most suitable speed for reliable working." This refers to Mr. Creed's printer and is written in 1913, but in the present discussion Sir William Slingo says the figures which I give of 130 to 150 words per minute for Morse code printers is a liberal figure. Any unbiased engineer who examines the robust construction of a Baudot printer and the delicate, beautifully made parts which go to make a Morse code printer, can only come to one conclusion, especially when he is told that the speed of working of the two is in the ratio of 1:4. Mr. Creed refers to the "underlying fallacy of the favourite argument employed by the advocates of the 5-unit alphabet." I think my reply to Mr. Judd is sufficient, but I will re-state the position in other words. Every circuit of any considerable length will transmit a certain number of battery reversals (all best-possible conditions assumed), the number depending upon the line constants. The maximum possible number of letters can be signalled through

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such a circuit when an alphabet is employed having the shortest number of units (half reversals or semi-cycles) per letter. On long submarine cables we do not find an alphabet used which has the largest number of units. The exact contrary is the case. I regret that Mr. Creed has not mentioned the "several very good and sound reasons why the 5-unit alphabet does not and never can equal the Morse for printing telegraphs." I will be equally dogmatic with Mr. Creed and say that no printing telegraph employing the Morse code can hope for a permanent existence except, perhaps, for cable circuits where the Creed and the Fraser instruments are peculiarly applicable. The fastest printing telegraph circuit in the world—the New York-Boston circuit of the Western Union Company—employs the 5-unit code and works regularly day by day at 200 words per minute each way, quadruple duplex at 50 words per channel.

TABLE I.

*Comparative Operating Costs at the London Central Telegraph Office. One Week's Traffic.*

Baudot ... ..	0.254 pence per telegram
Creed-Wheatstone ... ..	0.312 " "
Hughes ... ..	0.320 " "
Wheatstone ... ..	0.419 " "

TABLE 2.

*Percentage of Delay on Six Days' Traffic.*

	20 Minutes or Less	Over 20 Minutes
Wheatstone, Wire No. 1 ...	48.0	52
" " No. 2 ...	74.3	25.7
Wheatstone-Creed... ..	43.3	56.7
Baudot ... ..	90	10

In reply to Mr. Creed's list of questions I must refer him to the officers of the Administration concerned for answers to (1), (2), (3), and (9).

The answer to (4) appears to me to be that, except for accidental causes, the general telegraph traffic of the country ceases at night. Markets, stock exchanges, and business offices are shut and the distribution of news by the Wheatstone has commenced. Any general business there is can be handled by Morse key.

(5) Morse apparatus is required for balancing when starting up, and service purposes when stoppages and derangements occur. I am not, however, aware that wires and staff are held in reserve, and, at all events, there is no necessity for the staff, as in the event of a total stoppage the multiplex operators are available.

(6) I do not think that this holds as a general rule. I only know of one instance.

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(7) Because the multiplex system is not yet sufficiently widely installed.

(8) I do not know that any determined effort has ever been made on the part of makers of multiplex apparatus to approach the newspaper proprietors.

At least three makers of multiplex apparatus have had to suspend the work of development and construction on account of their men and shops being required for other purposes. Otherwise the question and answer (7) might be very different. Were it not for this fact the Post Office figures for equal-letter systems in the Berne list would be probably considerably greater.

The discussion has revealed that the principal differences of opinion centre round the two questions: (1) Automatic versus multiplex printing telegraphs, and (2) equal-letter versus unequal-letter alphabets. Both these questions have what I may term a mechanical aspect and a traffic aspect. The mechanical aspect has been sufficiently dealt with both in the paper and in my reply to the discussion and there only remains the traffic aspect to consider. The traffic question may be resolved into two parts: (1) The handling of traffic at offices, and (2) its transmission over the line. It is to traffic officers that we must go for guidance for the first part; the second is within the province of the engineer. Tables 1 and 2 are taken from Mr. Newlands's 1913 paper.

No figures are available for the modern multiplex with keyboard perforators, cadence and speed free. On land lines we cannot use the cable code at anything above hand speeds because of the zero unit. Our choice is

therefore limited to land line Morse and the 5-unit code. I have already given two examples of the difference of efficiency between the two, and I conclude with the following further example:—

On the 2nd and 3rd May, 1905, comparative tests were made with Wheatstone and the 5-unit alphabet (Murray Automatic). A loop line was made up from London to Warrington via Birmingham. The results were the following: Wheatstone simplex, maximum speed 53 words per minute. At this speed letters such as "l" failed and it was necessary to reduce the speed to 30 words per minute to get "l" perfectly. The 5-unit system under the same simplex conditions gave 103 words per minute, but only by extremely careful adjustment, and there was no margin. Duplex Wheatstone gave 25 words per minute. The slightest increase in this speed rendered the signals unreadable. Duplex 5-unit system gave 53 words per minute perfectly and with good margin. These results confirm two things. The transmission equivalent for the 5-unit code is slightly greater than the same number of units in the Morse code, and the ratio of 8:5 for the two codes slightly favours the Morse. In America Continental Morse is taken as equivalent to 9 units. The smaller the number of units per letter the easier it is to secure a good duplex balance on a long line and for a given traffic.

An omission has occurred with reference to Fig. 74. At the transmitting end, when starting up, the two batteries shown should be disconnected by a switch from all but the 12 o'clock segments.

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## DISCUSSION ON

## "THE DESIGN OF HIGH-PRESSURE DISTRIBUTION SYSTEMS."\*

SCOTTISH LOCAL SECTION, 11 JANUARY, 1916.

Mr. A. PAGE: The author refers on page 125 to the increased application of high-tension distribution. I think we can hardly dissociate that from the power station, where turbines have combined with this outside work to bring about the success referred to. It is interesting to note that the author considers the area served should be as large as possible. In this connection Mr. Lackie in his recent Presidential Address to the Institution of Engineers and Shipbuilders in Scotland said that in his opinion the electricity supply of the whole of Scotland could be best undertaken from three power stations. As to the essential characteristics mentioned under "General Principles," I should be inclined to place freedom from interruption of supply as the second, and to transfer suitability of supply to the last place. With regard to the cost of operation in sub-stations, in Glasgow we are employing girls as switchgear attendants and we find that they do the work very satisfactorily. I think we are fortunate in that we are not troubled with the necessity for considering overhead lines. What the author says regarding overhead lines will hardly make for the peace of mind of any engineer contemplating the adoption of that method of distribution. In his remarks on switchgear the author again confirms what has been brought home to many of us: that the most important part in the switchgear is the circuit breakers, and that the amount of load current to be carried has really very little to do with the design. The gear must be capable of dealing with heavy short-circuit currents, and in this connection too much cheap sub-station switchgear has undoubtedly been installed. I wish the author could tell us his experience with switches fitted with air cushions and vent pipes open to the atmosphere, since we have no such switches in this neighbourhood. I should also like to know whether the Hunter-Shand switch has been commercially developed and what results have been obtained with it. There has been a great change of front upon the question of reactances, referred to on page 128. When Mr. Peck was here two years ago I admit I was very favourably disposed towards the use of reactances upon feeders and between sections of busbars, but I am now a convert to the author's views. In the summary on page 129, I would only refer to the third fault, viz. that due to mistakes in operation. In our experience this has been the greatest source of trouble but it has occurred mostly in the sub-stations. I am afraid that interlocking gear leads to a good many complications, and would certainly not prevent an operator switching in an alternator dead out of phase. One rather serious fault was brought about through a feeder isolator being opened on a working feeder instead of on the adjoining feeder which had been made dead. The link opened the arc all right, but the operator lost his nerve, threw the link down to the earth connection, and at the same time an earth was

developed upon the other phase and this led to a shut-down. The most interesting part of the paper in my opinion is that referring to the economic section of mains. The author must have spent a great deal of time on the calculations, but I am afraid that the data obtained is of very little practical use. When we are called upon to give a supply to a new consumer we rarely take into serious consideration the exact requirements of that particular consumer. We have standard sizes of cables and one of these is selected. The selected cable may have little relation to the immediate load, but it is of course laid down for flexibility and extensions to other works in the same district or on the route of the cable. Fig. 6 on page 132 gives helpful information about the economical cross-section at different ratings. I have plotted a curve of ratings for various sizes of cable which we work to, and it is interesting to see that this curve runs almost parallel with the curve for underground mains up to 11,000 volts as given by the author. Our ratings are somewhat higher, but it appears that, using the simple rules, we have arrived at very much the same result although still a long way off the limits imposed by the German rules. There is a remark at the bottom of the second column of page 130 which I should like the author to explain. He says "the losses have to be transmitted, on the average, over say two-thirds of the distribution system and should therefore bear two-thirds of the fixed charges of the latter." The author in making that remark does so without explaining his method of arriving at the value of the losses, but having obtained the cost of the losses at the power station he says that to these should be added the fixed charges of two-thirds of the distribution system. It seems to me that we are meant to infer we have to add two-thirds to the initial cost of the whole distribution. Obviously that is not what was intended, but that is how it reads. The reference to root-mean-square at the top of page 131 is misleading; at least it was to me the first time I read the paper. I took it to mean the root-mean-square value of one period, but what is meant as I take it is the square root of the mean of the squares of the average current for, say, 24 hours. The formula at the bottom of page 131 for ascertaining the annual value of the losses per mile of 3-phase mains is not clear. I should like the author to explain how he obtained this formula. A proper lay-out of any distribution system is in my opinion only possible if the interconnected system is employed. This system is accepted universally, and the fact that there have been many attempts to imitate the Merz discriminative protective gear is a sign that engineers do not want any other system. To the summary of advantages of the interconnected system I think we might add that such a system leads to better economy in large power stations where without an interconnected system there might be a tendency to run the power station in four or five parts separately in order

\* Paper by Mr. J. R. Beard (see pages 125, 225, and 291).

Mr. Page. to avoid serious trouble when faults develop outside. The diagram of the North-East Coast system leads one to wonder how the regulation between power stations is managed. What instructions are given to the station engineers as to the distribution of wattless current between the power stations? How is the load between the sub-stations ascertained so that serious overload on certain cables is avoided? Are ammeters or indicating wattmeters installed on every feeder panel? Or is the risk of overloading not thought to be serious? In Fig. 10 a line is given to represent the ideal main with no self-induction. That line is inclined to the horizontal. The author has told us he was only taking into account resistance; if so, I imagine the line should be horizontal, but I take it it is inclined because of capacity. On the basis of Table 6 I have worked out corresponding figures for the Glasgow system. These figures are as follows:—

System of voltage actually adopted...	6,600 volts
Number of switches per mile of main	278
Average max. kilovolt-amperes per mile of main	... .. 1,000
Most economical system voltage	... 8,000, i.e. 1,400 volts above the voltage which we are actually employing; probably that is due to the very concentrated nature of our load, and it shows that sooner or later we must adopt higher voltages if we are going to deal with heavier loads.

The upper and lower limits for system voltage in Glasgow are 12,000 and 5,000.

Mr. F. H. WHYSALL: I am more particularly interested in the portion of the paper which deals with protective gear suitable for immediate application to systems which have been operated up to the present time without such gear, and I think perhaps it would be of interest if I gave particulars of some experience with protective gears which proves that those of the balanced type are extremely effective and satisfactory in operation. I remember being present when a man accidentally earthed a phase on a system with balanced protection, and the latter was so effective that nobody near the fault realized from what was seen that anything had happened at all. In this station two motor-converters of the La Cour type were running at the time on the high-tension bars, and the man who had caused the earth immediately went to ascertain the voltage and thought that nothing had happened. The earth wire was in the man's hand and I would imagine (having had actual experience of such an occurrence) he ran grave risks. However, he saw that the pressure was still on the busbars and he came to the conclusion that there was some mistake somewhere and that he had done nothing. The explanation was, however, that the continuous-current side of this sub-station was in parallel with the continuous-current side of another sub-station, and the voltage indicated by the instrument at which he looked was fed back from the low-tension system. Of course he was speedily notified that he had put an earth on the system and had opened the group switch; the current passing, however, was so small that there was no indication of anything having happened at the place where the accidental earth was made. That made a very great impression on my mind and I thought what a perfect system of protection the balanced protective gear was for

such an occurrence. It is easy to apply: in Manchester it meant the addition of another current transformer and a relay. Nothing more was needed in many cases. Then there is the Merz-Price gear. I think we all agree that that is an extremely satisfactory system of protection, and we are more interested in these than in those particularly indicated by the author, because of the possibility of applying them to systems which are already in existence and have been designed without any thought of protection such as is desired to-day. Protective gear first came under my notice during a visit by a friend who was in charge of overhead lines in South Africa. He described to me his tribulations and trials from storms and breakdowns until he himself decided to manufacture a form of protective gear. I remember he was reduced to the use of old kerosene tins and a water resistance to earth the star point, but the results were exceedingly satisfactory.

Mr. E. SEDDON: Regarding the earthing of feeders, I think it is desirable first of all to earth these through a potential transformer to ascertain whether a feeder has been properly disconnected from all sources of supply. In one case, I arranged a knife switch in circuit with the earth-plate, and across this switch connected a potential transformer. When a feeder was put out of service and required to be earthed, it was connected to the earth bar with the knife switch open, and tested for pressure; if no pressure was showing, the knife switch was closed.

Mr. D. A. STARR: The author's remarks about overhead lines being more subject to breakdown than underground mains, particularly appeal to me. I had that same impression myself a few years ago, but my subsequent experience with over 50 miles of 11,000-volt overhead transmission has been sufficient to satisfy me that when such lines are well designed and regularly patrolled they are quite as reliable in service as underground cables, especially in districts such as Lanarkshire, where ground subsidence are prevalent. We have had our troubles, but I must say that with a good balanced protective-gear equipment we have not had any trouble for a considerable time, either on extra-high-tension overhead lines or underground cables. The author refers to the difficulty of obtaining wayleaves. I know this has been a source of great trouble and inconvenience in the South, and that the very large sums demanded for overhead wayleaves have materially affected the capital cost, so that when the extra annual upkeep and maintenance are taken into consideration there is no advantage. I think I have cause to congratulate my staff on the manner in which they have been able to negotiate line wayleaves. We find that by approaching estates and proprietors and pointing out the undoubted benefits of a line extension in enabling them to open up and feu the land, and also to work the minerals which could not otherwise be developed so cheaply, the result is that we are able to secure with few exceptions better conditions than those prevalent in the South. Another point is the author's reference to busbar faults. Of course balanced protective gear does not take care of such faults, and the only method I can conceive of overcoming this to some extent is in the design of switchgear. I really cannot see the necessity of making switchgear absolutely fool-proof for operation by employees of ordinary intelligence, who should have sense enough not to open and close switches at a wrong time. I know it is frequently done, but I am pleased to say we

experience very little trouble from such a cause. I am interested to note that Mr. Page has adopted female labour for sub-station work. To come back to the design of switchgear, I know it is a matter which has been the subject of much investigation by eminent engineers on both sides of the ocean. On the other side it has been particularly so, as they operate at much higher pressures than we do here. My own staff has designed extra-high-tension switchgear which has proved in operation to be superior to some extent to a great deal of the switchgear manufactured by makers in this country.

Mr. W. C. BEXON: I should like to ask the author what particular apparatus is used on the North-East Coast system for keeping the voltage constant upon the outlying districts.

Mr. W. W. LACKIE: The paper is of particular interest to me at the present time when the Glasgow Corporation are designing an extra-high-tension network. In the system advocated by the author there is a similarity to our low-tension network. We have made a practice now for many years of laying down a definite size of network in each street irrespective of the immediate demands, and as the load grows in any particular district we lay a new feeder to a point midway between two adjacent feeders. The system of interconnecting extra-high-tension mains has only been rendered possible by the work of Messrs. Merz, Price, and Hunter. I agree with the author that main switches should be of the very best design as they have to stand enormous strains. We have had cases of main switches being closed on a short-circuit. Looking at the diagrammatic lay-out of the different distribution systems on which the author has based his conclusions, it appears to me that if the station is not central to the area to be supplied but is situated at one of the boundaries of the area, scheme (a), Fig. 9, would not show the same saving as would be possible with scheme (b). In scheme (a) the whole supply is dependent on four mains. In the event of one main breaking down, the other three would be overloaded to the extent of 33 per cent. In Glasgow the problem is rather different from that discussed in the paper as we are dealing with sub-stations each containing between 5,000 and 6,000 kw. of plant, which necessitates at least one feeder to each sub-station.

Mr. J. R. BEARD (*in reply*): I quite agree with Mr. Page that much of the success of high-pressure distribution is due to the development of turbine plant, but at the same time it is high-pressure distribution which has in the first place created the demand for larger generating sets. I am glad to note that Mr. Page joins with other engineers connected with large systems who have spoken on the paper, in generally confirming the main conclusions regarding the importance of switchgear, the economy of the interconnected system, and the consequent necessity for reliable feeder protective gear. The experience of the North-East Coast undertaking is shown not to be unique, and I trust that the engineers of smaller but growing systems will be encouraged to pursue a far-sighted policy in designing their extensions, as this will undoubtedly react to the general benefit of the industry in the future. While air cushions and vent pipes on switches have their uses, the best commentary on their ability to prevent switch explosions is the experiment I described in my reply to Mr. Wedmore.\* The Hunter-Shand repulsive-arc switch has

been developed commercially and the experience with it Mr. Beard has so far been satisfactory, but it is too soon for any definite claim to be based on its actual operation. Mr. Page evidently feels that interlocking on switchgear is desirable, but he is rather afraid of the complication. I think, however, that an examination of actual interlocking schemes which have been developed will convince him that when boldly tackled the complication is negligible. It is certainly not nearly as complicated as the interlocks on railway signalling systems, which operate satisfactorily. I agree with him that it is not practicable to lay out a commercial distribution system on mathematical lines, but I think that my somewhat theoretical treatment of the subject enables certain tendencies to be clearly grasped which materially assist in the problem of laying out an actual system. In considering the heating curve given in Fig. 6 it must be remembered that it does not represent the continuous heating current. If the cable had an infinite heat capacity the R.M.S. current over the 24 hours would be the limiting feature from the point of view of carrying capacity. On the other hand, if the cable had practically no heat capacity the limiting feature would be the maximum current. As an approximation to actual conditions I have assumed the mean between the R.M.S. and maximum currents to be the current which if applied continuously would give the same temperature rise as the variable current which is actually flowing in the cable. I am sorry my use of the term R.M.S. current was not quite clear. As Mr. Page surmises, it refers to the whole 24 hours, and in this sense is in general use in connection with the rating of traction motors.

The point raised in connection with my remarks as to the value of the losses on page 130 is due, I am afraid, to loose wording. If the words "per unit" are added to the sentence Mr. Page quotes, the meaning will be quite clear. The formula at the foot of the left-hand column on page 131 is of course only applicable to the particular case considered, viz. a feeder with a 40 per cent load factor forming part of a system with a 50 per cent factor. With a 40 per cent feeder load-factor the average feeder current is  $0.4 I$ , where  $I$  is the maximum current. From Fig. 4 the R.M.S. current at this load factor is shown to be  $1.25$  times the average current, i.e.  $0.5 I$ . The resistance of each of the three phases per mile is  $0.04317/A$ , where  $A$  is the sectional area in square inches, this value allowing for hard-drawn copper on overhead lines and for the lay of the cores in cables. Hence the losses in units per mile per annum for all three phases are:—

$$3 \times \frac{0.04317}{A} \times \frac{(0.5 I)^2}{1,000} \times 8,760 = 0.284 \frac{I^2}{A}$$

With the system load factor of 50 per cent, the value of the losses was found to be  $0.25d$ . per unit, from which it follows that the annual value of the losses per mile of 3-phase main is £0.000296  $1/A$  as stated.

The regulation of wattless current and load between the generating stations on the North-East Coast system is carried out to the instructions of the "system engineer," who is in telephonic communication with each generating station and sub-station and has complete control of the operation of the system as a whole. Ammeters are installed on each feeder so that any overloading of feeders is quickly apparent. In a few instances it has been found

\* Page 232.



is large. This is certainly not our experience; otherwise we should not continue erecting overhead lines for important trunk mains, as we are now doing. I cannot agree with Mr. Starr that switchgear design is more advanced in America than in this country. This may have been the case 10 years ago, but judging from their technical literature and from conversations I have had with engineers who have been over there, I think to-day the position is reversed. This seems to be largely due to

one of the main feeders on the interconnected systems Mr. Beard. breaking down, and the effect of the power station not being in a central position. In all the network arrangements sufficient copper has been provided to enable any one feeder to be out of commission without limitation of the supply to any sub-station. Usually the overload margin of the cables was sufficient, but where this was not the case a section larger than the economical one was allowed for. The position of the power station was, I think, the

TABLE A.

Nature of Modification to the Typical System	Type of System	Reference to Fig. C	No. of Switches	Mileage of Mains	Annual Cost, £	Percentage Increased Cost over Corresponding Inter-connected System
None	Interconnected	(a)	64	32.0	4,752	—
	Series-radial	(b)	96	61.2	6,075	27.8
Power station on boundary of area	Interconnected	(c)	60	30.8	5,182	—
	Series-radial	(d)	90	79.7	7,730	49.3
Power station outside the area	Interconnected	(e)	62	47.2	8,805	—
	Series-radial	(f)	100	177.7	16,328	85.4

the vogue for reactances which has had the effect of arresting switchgear development in America.

Mr. Bexon asks for particulars of the means adopted for regulating the voltage in outlying districts. This question was also raised by Mr. Watson during the discussion at Manchester and I would refer him to my reply on that occasion.\*

Mr. Lackie has raised two important questions in connection with the various modifications to the typical system, which I dealt with in Table 3 and Fig. 9, viz. the effect of

\* Page 242.

one important variable factor which was not specifically dealt with in Table 3, but on page 138 I mentioned that the power station at the centre gave the least favourable comparison for the interconnected system. Actual figures are, however, more convincing, and these are given in Table A, the corresponding diagrammatic lay-outs being shown in Fig. C. The only modification to the typical system is the alteration in the position of the power station; the sub-station positions, spacings, and loadings remaining constant. Table A and Fig. C should be considered as complementary to Table 3 and Fig. 9 in the paper (page 136).

# YORKSHIRE LOCAL SECTION, 12 JANUARY, 1916.

Mr. H. H. WRIGHT: The subject of this paper is of very special interest to engineers in the North of England. In Yorkshire not only have we one of the largest power-distribution systems in the country, and one which is growing in size and importance every year; but also nearly all our larger supply undertakings in this district have had to install high-tension plant in order to transmit electric power more economically and to cope with the increasing demands of their customers in the outlying districts. In many Yorkshire industrial districts the demand for power has grown at such a rate in the last few years that station engineers have found difficulty in keeping pace with it, not only in the duplication of plant, but also in high-tension mains. Consequently, many of the feeders recently laid are already overloaded, new feeders and transformer stations have had to be installed, and many questions have arisen such as those mentioned in the paper; for instance, whether to use the split-conductor system for new feeders, and whether the increased demand would be better met by laying down a new transformer station and feeder or by interconnection with the existing network, or by both. These ques-

tions can only be answered by experience and with the aid of such papers as this, which contains the results of many years' practical working. On page 129 the author refers to the question of the depreciation of underground cables and mentions 22½ years as the period upon which Fig. 1 is based. This period appears to err, if anything, on the side of safety, especially in view of the report of the Committee appointed last year by the Council of the Institution to investigate the question of the life of underground cables.\* On page 133 the author emphasizes the importance of selective switchgear. In the lay-out of a distribution system it is important to realize that it is not the first cost of switchgear which is so important, as the fact that by the choice of suitable discriminating gear a saving of many times the cost of the gear may be made in mains, etc. From the point of view of capital outlay as well as freedom from interruption of supply, selective switchgear would therefore appear to be very important. The author makes out a very strong case in favour of core-balancing and a split-conductor system of protection, but I think there are many existing systems to which the latter cannot

\* See page 63.

Mr. Wright: be applied; for example, the case of two overhead feeders in which the ohmic resistance and reactance are very different owing to a difference in route. I should also like some information in regard to the core-balancing system of protection. Assuming that every 3-phase power system is to some extent out of balance, and therefore that every feeder is also out of balance—in some cases considerably so—and also bearing in mind that the action of the apparatus depends upon this out of balance, how is it possible to discriminate between a leak and an unbalanced load? These devices being adjusted to operate at a few amperes, it would seem probable that the relay might release the circuit breaker unless the out-of-balance current of the feeder is known and allowed for. I am glad to see that in his conclusions the author expresses a caution against the use of the information contained in the paper without taking into account the many other factors which are bound to demand consideration in the design of high-tension distribution systems.

Mr. J. E. STORR: I am pleased to note the author's remarks as to the development of high-pressure distribution. It is no longer high-pressure transmission; distribution direct to a consumer's terminals for transformation on the site is undoubtedly the method by which we shall have to transmit power for our larger loads in the future. The general utility of that high-pressure transmission would, however, probably be enhanced if it could be standardized on the higher voltages, instead of there being so many 2,000-, 3,000-, and 6,000-volt systems. If we could standardize our gear for 11,000 volts I am sure all of us would be better able to cheapen the cost of distribution. After all we have heard of late years regarding reactance coils I am pleased to agree with the author that to take protection behind a second line of defence rather than to have our switchgear designed to do its proper work is the incorrect attitude to adopt. I am afraid that the disadvantages under which overhead lines apparently suffer do not allow them to show up very well in the paper. One point, I think, in favour of overhead distribution is that it is undoubtedly the best method of dealing with the early development of an undertaking which has a large area to supply. If the supply area be developed by the cheaper method of overhead lines, although there may be the risk of some little disturbance it certainly allows the area to be developed more quickly and a careful and better-known system to be installed at a later date, preferably with underground cables and protective apparatus. The interconnection of sub-stations by feeders, and protection on either the Merz-Price or split-conductor systems, are, I think, undoubtedly the correct methods; but I have some difficulty in understanding the process of development. If we take the author's Fig. 9 (a) on page 136 we have the interconnected system shown there to every advantage. What would be, however, the proper method of taking the next step in order to proceed from (a) to (i)? Would the sub-stations on the fringe of (a) be fed by a single cable until such time as it was necessary or advisable to add two more legs to the square? I should also like to know whether an attempt has been made on any serious scale to develop the split-conductor method of protection on existing duplicate cables. I refer, of course, to cables laid in the same trench and of the same sectional area. The author, in his concluding remarks, advocates very

strongly by figures and in the text the use of higher Mr. voltages; and in my opinion the areas served by such higher voltages will undoubtedly increase rather than remain stationary. In the figures for switchgear in the last table, however, the author allows less than three-quarters of a switch per mile for the 20,000-volt work. Has he only allowed for the protective switchgear? I fear that the splitting up of a 20,000-volt main so as to provide a lower voltage for economical use between sub-stations would mean more than the number of switches allowed for intermediate sub-stations.

Mr. W. LANG: I think this paper will perhaps carry us a Mr. step further towards the standardization of power distribution. In connection with the author's attempt to justify the formula on page 129, the point he makes is that the formula is usually not strictly adhered to because engineers are rather afraid that it is inconsistent with carrying capacity and voltage-drop. Let us read in conjunction with that opinion one or two other statements which the author makes. He says on page 131 "it follows that it is not sound practice to cut the section of mains too fine, more especially since it is a most expensive matter after a main is once laid to increase its carrying capacity if this should prove too small"; and again on page 133 "that it does not pay normally to operate cables at the maximum current density allowed by heating-limits is of interest, since it means reduced voltage-drop per mile and consequently an increased radius of distribution for a given voltage." Apparently, therefore, the author cuts the ground from under his own feet by proving that the formula cannot be applied in anything like a concise or accurate way. As a matter of fact, I think all practice has shown that the estimates of the probable demands that will be made for electrical power on a certain route often prove within a very short period to be much less than the actual requirements. This, of course, has been particularly the case during the present war, when loads have come on the mains that were never anticipated by any of us. It thus brings one back to the point whether it is possible to lay out a scheme on the basis of a formula for the most economical size of main. Is not this size of main more dependent on a flash of inspiration as to what will be the ultimate demand for power on a given route? This brings me back to the concluding paragraph of the paper wherein the author says it is undoubtedly the case that experience instead of a strict adherence to formulæ has to be depended upon for success in the calculation of these lay-outs. Apart from the paper, the lantern slides shown by the author indicate to me that the original lay-out, or even the lay-out in 1910, of the North-East Coast system would not by any means meet the demand which had now been found necessary in 1915. At the same time I appreciate the difficulties with which the author has had to contend and the great amount of work that must have been put into this paper in order to obtain the tables and curves. In view of the author's statement near the bottom of page 131 with regard to the effect of variations in the prices of copper and lead, managers of supply undertakings can now console themselves with the knowledge that though the cost of copper should increase to £120 per ton, ordinary variations in metal prices have a relatively negligible effect. In connection with the point that Mr. Wright raised, I think the author does not refer

to the life of a cable, but to the replacement of a cable. Is the author sure that to allow a scrap value of 20 per cent for overhead lines is fair as compared with underground mains? I doubt very much whether the scrap value of an overhead line, which, I take it, includes poles, cost of labour of erection, etc., can be taken on as high a basis as with cables laid underground. I should expect the scrap value of the copper and lead of underground mains to be more than that of the total cost of the overhead line.

Mr. A. R. CHAYTOR: The author remarks that the formula for finding the most economical cross-section of conductor is seldom used in practice and he gives reasons for its lack of use. I think that the apparent general neglect of the formula is best explained by the curve in Fig. 5 and the author's remark that throughout quite a considerable portion of the curve the annual cost is practically the same, this being further emphasized by the additional curve showing the slight difference in cross-section when the system load-factor is reduced 10 per cent. When this is taken into account, and also the fact that in practically every case the majority of the units of the formula are only assumptions—so that after solving the problem and obtaining an answer to two or three places of decimals we may find that the sizes of cables as manufactured are 10 per cent larger or 15 per cent smaller in sectional area than the one calculated to be the most economical—it is easy to understand the usual neglect of the formula in favour of the rule-of-thumb basis of "1,000 amperes per square inch," modified in accordance with a common-sense view as to the ultimate use of the particular cable. Regarding the assumed life and recovery value of overhead lines, I am in agreement with the last speaker, that 20 per cent of the original cost after  $17\frac{1}{2}$  years' use is much too high, 10 per cent in my opinion being nearer the mark. The assumed value in the case of the underground cable is more reasonable; for I consider that after 20 years' use the cable would still have a useful life of several years, and would certainly be worth 20 per cent of its original cost. There is one little point I should like more information about, and that is, the reason for the apparent neglect to take advantage of the possibilities of laying underground mains across fields. The author states that one of the reasons for underground transmission being more expensive than overhead transmission, is that with the former it is necessary to keep to the longer and more devious routes of the roads. I cannot see why this could not be avoided by laying the cables along the roads where convenient, and then across fields where the route could thereby be shortened. An underground main would cause less obstruction and be less objectionable to the farmers, and, owing to the low costs of trenching, would cost only slightly more, since the high cost of underground mains in comparison with overhead lines is usually the result of laying cables through streets and roads with expensive pavings. Mains laid entirely underground would certainly be more reliable; for whatever the author says as to "serious" overhead-line breakdowns being only twice as numerous as those on underground cables, I think the number of actual interruptions on overhead lines certainly preponderates, otherwise there would not be such universal and consistent prejudice of operating engineers against overhead lines. I presume the author's

intention in setting out the diagrams in Fig. 9 was only to show the theoretical considerations to the best advantage; for there will be great difficulty in retaining any particular formation in practice owing to the uncertainty of the direction of the ultimate development from a small system to a large one. Thus in practice it might frequently happen that a system of the form illustrated in (a) Fig. 9 would develop in form like (g), and then open out again like (a).

Mr. J. SHEPHERD: I think the author does not give full value to the overhead system. Certainly in this country it is not used to anything like the same extent as in other countries. At Zurich overhead lines have actually been erected over a distance of something like 80 miles. In their wild mountainous country they found that the overhead system would transmit safely all the electrical energy required for lighting the town, and also for power purposes and the tramways. Two lines are run over mountainous country for 80 miles at 80,000 volts. The same system will shortly be introduced in Berlin; all the inner stations in Berlin are to be shut down and the entire supply—which will certainly amount to 300,000 kw.—will be transmitted by an overhead system. If overhead systems can be used abroad with such boldness I think the time will come when we shall have to design overhead systems in this country for higher voltages and greater power. When dealing with very large amounts of power I certainly think that inductance should be provided either intentionally by reactance coils in the machines themselves or in the transmission system. Overhead lines certainly have the advantage of possessing higher inductance. Perhaps smaller supply systems do not require this, but very large systems undoubtedly do. The question of lagging current can be got over with overhead systems by rotary condensers, which are simply over-excited rotary converters. Dealing with switchgear, I think there is no doubt that in order of reliability the large steam-turbine comes first, and secondly comes the generator, the bottom of all being the switchgear. With our present knowledge I think we cannot get switchgear which is as reliable as the mechanical plant of an electrical system. In regard to the life of mains, the author is rather understating it at  $22\frac{1}{2}$  years. The Treasury usually allow 25 years for the life of a cable, and a life of 40 years has been suggested by engineers of experience. If the cables are laid on the solid system, where no water comes into contact with the lead I do not see why they should not last 100 years; whereas if cables are drawn into ducts and the water is foul, the cables may not last 10 years. It is purely a question of the life of the lead sheathing. A good deal has been said about the calculation of economical area. If we possess all the data, we can calculate fairly accurately, and when I was younger I used to go in largely for such calculations. Sub-stations were estimated to be of 1,000 kw., but to be quite safe they were taken at 1,500 kw., and it was not very long before the 1,000-kw. station became one of 2,000 kw. or 2,500 kw., so that all our calculations were useless. The calculations would have been perfectly correct if we had had all the data. Not having data, judgment and experience come in. That is one of the greatest difficulties in making cable calculations: we do not know the problem we have to solve.

Mr.  
Chaytor.

Mr.  
Shepherd.

Mr.  
Shepherd.

To ascertain the most economical area graphically is very simple. We merely draw a series of rectangular hyperbolae corresponding to the different numbers of units transmitted and the various costs per unit. Over this lay a tracing showing a series of cable costs for various cables, and the correct area can then be determined in a few seconds. There is one slight correction which is not mentioned by the author in getting out the most economical area; he appears to have made no allowance for the capital value of the plant which must be provided to compensate for the losses in the cable. If we lose 1,000 kw. in transmission we not only lose that power but we also lose 1,000 kw. of plant. As a matter of interest, the system shown in Fig. 12 (a) was, I believe, first suggested by me at the end of 1901 for certain of the earlier sub-stations of the London County Council Tramways, whereby each sub-station was interconnected to the two adjoining ones. The system worked very well and was extended to the entire system, costing something like £250,000 for high-tension cables.

Mr.  
Hartnell.

Mr. W. HARTNELL: The design of any system for the economical supply of power over a large area whether by electricity or any other suitable medium such as water, compressed air, or gas, may also be viewed as a problem of mechanical engineering. Where the original supply of power (or energy) has been local, the development to more distant areas has almost necessarily been on the following lines:—At first the power was supplied from a central station at a low pressure suitable for immediate use. As the areas to be supplied have become larger and more distant the power has been supplied to sub-stations at higher pressures, from whence the pressure has been reduced for the supply to the consumers. Next, when it has been found necessary to supply power to still more distant sub-stations a still higher pressure has been necessary. Meanwhile many consumers have been able to receive power at much higher pressure than was originally thought to be practicable. Hitherto in the design of extensive high-pressure distribution systems, engineers have been too often hampered by the "wait and see" policy of their employers, instead of being allowed free scope for their skill and foresight. This paper, in the first place, takes a broad theoretical view of the subject, illustrated by diagrams showing different methods of laying out a system of supply, and also diagrams to indicate the most economical section of mains. Abstract theoretical deductions must be received with caution, but in this case they are trustworthy and valuable because they are based on practical experience in connection with the development of one of the largest electrical power supplies in this country. Engineers may therefore accept them as suggestive guides in the lay-out and development of future electric supply systems. Diagrams are given investigating the most economical means of conveying power, from the point of view of position, aerial or underground, how insulated and protected, and at what electric pressure. These may save much time in preliminary investigations, but the actual decision from the point of view of economy will probably require several trial calculations, taking into account special factors necessarily left out of all abstract investigations. When power is supplied from one central station, mechanical engineers have relied on single cables for each phase, together with

good design, good material, and good workmanship. A few years ago the idea of connecting the power house with diverse sources of power at a distance, and interconnecting them to all the numerous transformer stations, would have been deemed so liable to interruption as to be most undesirable. The paper gives an outline diagrammatic representation of the accomplished fact with interruptions rendered improbable. The duplicate cable systems for insuring unbroken circuits have been described in previous papers, but the outline diagram showing this successful application is new. Duplicate connections with safety arrangements are evidently essential for safety in such a system, for, as the author remarks, electric power would be dear as a gift if merely once a year the supply to a large works was stopped for a few hours. We are told that the extra cost of the safety arrangements is an unimportant factor. Bare overhead conductors appear indispensable for conveying power at a reasonable cost to distant areas. Those of the Yorkshire Power Company extend for miles. In America overhead conductors convey power at a very high pressure for hundreds of miles. In view of future as well of immediate requirements, it would greatly benefit the country if Parliamentary powers were given for systematic planning of routes for electric conductors over county areas, together with compulsory wayleaves.

Mr. J. H. SHAW: The author has undoubtedly made out a good case for the interconnected system, and I want to say a good word for the change-over "tee" system for use on a moderately large network. In the undertaking with which I am connected, this system has been in operation for to years, and during that period there have been six faults on about 60 miles of extra-high-tension mains, only one of which has been a true cable fault, the remainder being caused by men doing excavations and other work on the road. Taking the above into account I do not think anyone can say that we could have given a more reliable supply, even with the most complicated interconnected system. Unfortunately, distribution systems are not designed, as there is very seldom any scope to carry out ideals, because owing to economic reasons the extension is generally a compromise. When an application is received the anticipated revenue is estimated as closely as possible; mains have then to be laid so that the annual capital charges on them are well within this amount. We have had our ideals, but up to the present we have not been able to justify the extra cost in installing an interconnected system. If two applications are received at the same distance from the power station, and if we assume the natural routes of the mains are at an angle of 45 degrees to each other, I estimate that the ratio of the cost of a duplicate main system to that of an interconnected system is 2.1:2.4. The author states that with an interconnected system greater advantage can be taken of the diversity factor than in other systems. Unfortunately, in a city where the trades are all similar and the works start and stop at the same time the diversity factor is almost negligible. From the readings of the maximum load carried by any feeder and also of the maximum loads at each sub-station on that feeder, I find that the highest diversity factor is 1.25. I should like the author to tell us the period of time during which the 23 faults mentioned in the paper occurred, and how many

faults there were during this time due to faulty operation of the protective devices. On page 135 he says that 10 per cent added to the cost of the switchgear will pay for protective devices. I find that it would cost us considerably more than 10 per cent extra at the present time. We are paying approximately £6 for three current transformers, and I estimate that three similar current transformers suitable for split-phase working would cost £40, which is approximately the cost to us of one complete feeder cubicle, including oil switch and isolating links. With regard to Mr. Wright's remarks in regard to the life of cables and the period allowed for repayment of loans, I am glad to say that the Local Government Board now allow for cables repayments spread over a period of 25 years.

Mr. J. R. BEARD (*in reply*): Mr. Wright has appreciated and selected for special reference what I consider to be one of the more important conclusions of the paper, viz. that the savings which can be effected by suitable discriminating gear are many times the cost of the gear itself, so that its use is not to be regarded as a luxury but as commercially desirable. He has, however, rather misunderstood the type of protective gear which I called the balanced-current system with pilot wires. It is perhaps more usually referred to as the Merz-Price gear and is quite different from the core-balancing system which he refers to. The latter is not suitable for general feeder protection, although it is very useful under certain limited conditions.\* The reason why core-balancing gear does not operate with unbalanced 3-phase loads is that although the R.M.S. currents may be unbalanced the sum of the currents in all the phases at any given instant is zero unless some current is returning via earth. I have already dealt with the application of protective gear to existing networks, which is referred to by both Mr. Wright and Mr. Storr.† In the particular case, which Mr. Wright mentions, of two parallel overhead feeders of different ohmic resistance and reactance it is possible, with care, to produce an artificial balance, but such procedure is not to be recommended unless the differences are small percentages. Both Mr. Wright and Mr. Shepherd refer to the rate of depreciation I have allowed on cables and overhead lines. This question is fully dealt with in my reply to the discussion before the Institution.‡

I am glad that Mr. Storr emphasizes the fact that high pressure is now used for distribution. I think it is becoming fairly generally realized—only perhaps we have been able to realize it more clearly on the North-East Coast where the development has been so rapid. He suggests standardizing voltages, but, while I agree with the advantages of standardization, I doubt whether one could usefully standardize voltages at present. Fortunately, transformation of voltage is comparatively cheap, but this is not so in the case of frequency. In many districts about the country one finds two or more different frequencies side by side, and of course the London area is notorious. It is questionable whether when standardizing frequency any alternative choice should have been provided, but in any case I think a single frequency should in the future be made obligatory for all undertakings in any particular industrial area.

I am asked to describe how one would progress from

Fig. 9 (a) to Fig. 9 (i). Whether a single feeder should be laid to the additional sub-station or whether a portion of the loop should be completed would depend upon the consumer's requirements. In such a case one would usually endeavour to obtain the consumer's agreement to a temporary non-duplicate supply so as to have a free hand to lay the additional cables where they would in the future be most useful. Of course, in practice each case must be treated on its merits, and in very few cases is there any difficulty in deciding what to do. For example, quite recently a large amount of munition load has been connected up on the North-East Coast and it has been so easy to do it that the supply has been available some time before it has been required, although in many cases the load has been several miles from the power stations.

In Fig. 13 I have allowed for 2½ switches per sub-station for controlling the step-down transformers, in addition to the feeder switchgear, which I think is quite a reasonable figure, as in the majority of sub-stations only two will be required. Similarly the figures for switches per mile of main in Table 5 comprise both feeder and transformer switches.

In reply to Mr. Lang and the somewhat similar criticism of Mr. Shepherd, I quite agree that a distribution system is a rather indeterminate problem and that in practice economical sections cannot be worked to very accurately. My two general remarks which Mr. Lang quotes as an instance of my contradicting myself seem to me to do just the opposite. They give a practical basis on which to work, and I should certainly not have felt justified in making those two remarks without being able to base them on the theoretical investigations previously described. Again, as mentioned by Mr. Chaytor the curve on page 131 shows, as stated in the paper, that the economical section is not very definite, but I do not think this could have been assumed without investigation. Also, I certainly cannot agree with his statement that consideration of the economical section is evidently unnecessary as the results agree roughly with the old rule-of-thumb basis of "1,000 amperes per square inch." That rule was an early attempt to prevent overheating, and as soon as engineers found that on the smaller sizes of paper cables very much higher densities could be safely used, the rule became generally looked upon as entirely erroneous. I think it is by pure chance that this old heating rule happens to agree fairly closely with the economical section of high-pressure mains.

Mr. Lang points out that apparently the original lay-outs of the North-East Coast system in 1905 and 1910 would not meet the demand in 1915. No; they certainly did not, but there was this advantage that by using the interconnected system it has been possible to lay the additional copper exactly where it was wanted. In the early stages when the system was designed on a radial basis a good many of the cables installed were, quite rightly, much too big for the actual loads, with the idea that it would be a most expensive matter to increase them later and that it was advisable to spend a little extra capital in view of the probable future requirements. If one does that it is surprising how often the new load comes on the other side of the network, and many of these old radial cables are the worst loaded on the system. Fortunately, it has been possible to work many of them into the interconnected system and thus to load them up

\* See my reply to Mr. Whysall (page 382).

† See page 294.

‡ See page 321.

Mr. Beard. very much more economically than ever they were before. In other words it is found in practice that it is much easier to run feeders at their economical loading on an interconnected system than on a radial one.

With regard to residual values I only took account of the copper in the overhead lines and the copper and lead in the underground cables. In each case after deducting 15 per cent of the value of the material to cover the cost of scrapping, the residual value came out very close to 20 per cent of the original value. I assumed, of course, that the cable could be recovered at the same time that the new cable was laid.

I am acquainted with several cases where underground cables have been taken across fields as suggested by Mr. Chaytor, but as a rule it is more difficult and expensive to arrange wayleaves for them, and in open agricultural country cables have to be laid deeper than in roads. In the comparisons of the costs of cables and overhead lines I have taken the cost per mile in each case; if allowance is made for the saving in route length effected by overhead lines they would show up more favourably. In the case of cables I have only allowed a medium figure for trenching and in roads with a concrete foundation, or a special surface, cables would be more expensive than shown in Fig. 1.

I agree with Mr. Shepherd that at the present time if one goes to 80,000 or 100,000 volts there is no practical alternative to overhead lines, but I do not think in England we are at present faced with the problem of using 80,000 or 100,000 volts, although voltages up to about 40,000 are likely to be introduced in the near future. Three-core cables have been already developed for such a voltage, and by the time the higher voltages are required I trust cables will have been so improved as to be able to deal with them, since, however satisfactory overhead construction may be, it is necessary in this country to have underground cables in populous districts, and cables are also desirable in order to deal in a satisfactory manner with the ends of the overhead lines. While I think that in general the balance of advantage is against an artificial increase in the inductance of feeders, I agree that, if for other reasons overhead lines are used, there is some compensating advantage to be gained out of their higher inductance. If the power factor of a system can be kept under control by over-excited synchronous plant, as suggested by Mr. Shepherd, the disadvantages of feeder reactances can be avoided, but such conditions only obtain when a large proportion of the load consists of continuous-current traction or continuous-current distribution for domestic purposes. Mr. Shepherd mentioned that, in estimating the value of copper losses, allowance must be made for the capital value of the plant required to supply them. I have already done this and rather over half of my figure of 0.25d. per unit represents the fixed charges.

Mr. Hartnell suggests drastic legislation for wayleaves. Mr. Es. He has raised a very important point, and in view of the more general realization of the need for such legislation it is quite probable that action may be taken as soon as conditions are more favourable.

Mr. Shaw seems to have been fortunate with his distribution system, but I understand that it is all underground cable and is at a comparatively low voltage. On the average he appears to have one fault per annum per 60 miles of cable. On the North-East Coast system the cable faults are rather more than twice as frequent, but this is probably accounted for by subsidence troubles and the large amount of 20,000-volt cable. If, however, it is remembered that the mileage of the mains is over 700 and that a large proportion of this is overhead, it will be seen that it becomes very desirable to limit the disturbance which a fault causes, and no doubt as Mr. Shaw's system grows he will increasingly feel the need of automatic feeder protective gear. In connection with his difficulty in justifying the interconnected system as against the change-over tee system, I cannot do more than refer him to Table 2 in the paper. In the particular instance which Mr. Shaw mentions of two loads at equal distance from the power station along routes 45 degrees apart, I find the duplicate main system would still cost nearly 10 per cent more than the interconnected system; a result which is rather the opposite of his figures. It should also be borne in mind that this particular instance is a very severe test since the minimum size of system is being considered, while, as I have pointed out, the interconnected system shows up more favourably the larger the system.

The particulars which Mr. Shaw gives of the diversity factor of his load are most interesting, but with a larger area much better diversity factors would be obtained and also I should imagine that the textile trades have a particularly low diversity factor. The 23 faults referred to in the paper covered a period of about six months, and during this period (taken quite at random) there were no cases of faulty operation of automatic feeder protective gear. The figures which Mr. Shaw gives for the cost of current transformers are not properly comparable. Current transformers at £2 each would not be satisfactory on a large system, and so far split-conductor gear has chiefly been developed for large systems and the class of apparatus is accordingly expensive. If there is a demand for it in connection with lighter forms of switchgear, I have no doubt suitable apparatus will be quickly developed. My figure of 10 per cent was based on actual switchgear suitable for large systems, the approximate price being indicated in Fig. 12. I find, however, that in installing a protective system the pilot cable or the splitting of the conductors costs five or six times as much as the additional switchgear required, so that the cost of the latter item is not of so much importance as might be thought at first sight.

## DISCUSSION ON

## "THE PREDETERMINATION OF THE PERFORMANCE OF DYNAMO-ELECTRIC MACHINERY."\*

MANCHESTER LOCAL SECTION, 11 JANUARY, 1916.

Mr. L. H. A. CARR: In discussing a paper of this sort it is well to remember that the treatment of design naturally falls into two portions. The first is the academic or general side, which is comprehensive of many makes of machines; and the second is the specific side, or the application of constants and data for any given line of machines, based on the theories outlined by the general side. This division naturally only takes place in the more variable quantities (leakage, temperature rise, etc.) and not in the fundamental formulæ of magneto-electric phenomena. A paper such as this is the more valuable in that it gives formulæ of fairly general application and indicates the limits between which the individual designer is likely to find his constants. With regard to leakage, however, the method given by the author seems to err on the complicated side, as the expression contains four quantities. To determine, by means of a score or so of test results, what are the correcting constants to make these formulæ correct over a large range of sizes of machines is well-nigh hopeless, as each of the four variables may be changing independently. Some simpler general equation is therefore required to enable the individual designer to determine fairly easily the constants for his line of machines. I have found it possible in practice to calculate leakage by means of a formula containing only two terms, the first being simply proportional to the core length (a different constant being used according to whether the rotor slots are less or more than the stator slots), and the second giving the end leakage. Though it may be argued that this method should be less accurate than the author's, yet it works well in practice, and the determination of the two constants for use with any given line of motors is of course fairly simple. The author's formula for end leakage, with constant ampere-wires per inch, gives the leakage increasing roughly as the square of the pole-pitch. My own experience is that this power is too high; "pole-pitch raised to the power of  $1\frac{1}{2}$ " is probably high enough. The author suggests the separation of core and end leakage by comparison of tests of stators of different lengths. In this case the difference to be found is so small that it is difficult to determine it accurately, and I suggest that better results are obtained by comparing machines of the same core length and different pole-pitches. I cannot agree with the figures given by the author as to the large difference in end leakage between concentric and barrel windings, and I should like to know how the figures have been obtained. Instead of a difference of 1.4 to 2.45 (Table 2—barrel-wound rotor in both cases), which is a ratio of 4:7, the ratio 6:7 seems far nearer the truth. In this connection I would point out that the motor given in the table on page 251 has a concentric winding, whereas a barrel winding, according to the author's figures, would have a total leakage of 14 per

cent less, quite an appreciable amount and a greater difference than I have found in practice. Of course the reason for not using a barrel winding in the case considered is obvious, as the machine is wound for 2,500 volts. The core-loss curves given by the author on page 263 call for some criticism. It is not stated whether these are for continuous or alternating-current machines, but it is inferred that they hold good for both classes. Some two years ago I carried out a series of experiments on core losses and found that for a given frequency and flux density the core loss in a continuous-current machine was about twice that in an alternating-current machine. This fact is borne out by other authorities; for example, at  $B = 10,000$  and 50 cycles the author gives 0.05 watt per cubic cm., while looking up various other authorities I find figures ranging from about 0.05 to 0.07 for alternating-current machines. Turning to continuous-current machines, however, where perhaps  $B = 10,000$  at 25 cycles is a better criterion, while the author's figure is 0.02 I obtain the following figures from other writers:—Hobart, 0.035; Alexander Gray, 0.037; Schukkermann, 0.052; Whittaker, 0.052; Cramp, 0.061. These last figures I agree are high (0.04 being my own estimate), but I should like to ask the author whether these curves are borne out by experiment on continuous-current machines. Another point worth noting is the tailing-off of these curves at the upper end. While I have observed the same thing in asynchronous machines with cylindrical rotors, I find it does not occur with continuous-current machines, even up to extremely high apparent tooth-densities, but rather the reverse, the curves taking if anything an increased upward tendency. This phenomenon was observed in machines with armature conductors of small round wires, so that eddy currents in them were negligible. The probable explanation is that due to the high tooth saturation the shape of the flux-space curve under the pole-tip alters, the flux widening out, so that the curve takes a more square-shouldered form, with a consequent quicker change from a high positive value of  $B$  to a high negative value of  $B$ , and hence a higher eddy-current loss in the iron. This again leads me to doubt the reliability of the author's curves for continuous-current machines. I would also ask whether the scale of flux density is the real or the apparent value. I would also point out that the method of calculating the difference in temperature between copper and iron at the bottom of page 249, column 1, is not given in Appendix VI as stated in the paper. The figure used for the heat conductivity of micanite tube is, however, given in the author's recent book,\* so that this seems but an accidental omission. With the author's method of calculating temperature rise, Appendix VI, I cannot wholly agree. The equation at the top of page 264, column 2, for the

\* "Specification and Design of Dynamo-electric Machinery," page 224.

Mr. Carr.

watts dissipated from the cylindrical surface seems to be much too high for an induction motor. This type of formula gives good results for continuous-current machines with relatively large air spaces between the salient poles, but for an induction motor with small air-gap the figures seem much too optimistic. Working back from the figures given in the calculation sheet on page 251, the temperature rise of the stator inner face seems to have been taken at about 30 degrees C.; this I assume is to allow the 10 degrees difference between copper and iron mentioned in the paper. The heat produced (4,270 watts) must go from this surface to somewhere. Since the rotor has its own conductors producing heat, it seems unreasonable to expect this heat to be transmitted to and through the rotor. The only other place where the heat can go to is the air in the air-gap. Calculation of the quantity of air required to carry off this amount of heat may be made as follows:—

4,270 watt-seconds = 1,020 calories per second. Specific heat of air at constant pressure = 0.2375.

If the temperature of the air rises 20 degrees C., the weight of air per second must be  $\frac{1,020}{20 \times 0.2375} = 215$  grammes,

or 0.475 lb. The air will weigh about 1 lb. for  $12\frac{1}{2}$  cubic ft. at the working temperature and pressure. Hence the number of cubic ft. of air per second = 5.95. But the air-gap cross-sectional area =  $\pi \times 100 \times 0.2 = 62.8$  sq. cm., or 0.78 sq. in., or 0.0075 cubic ft. Therefore the velocity of the air through the air-gap must be  $88\frac{1}{2}$  ft. per second to carry off all the heat. Now calculating the water-gauge pressure necessary to force this air through the air-gap axially according to the standard formulae:

Inches of water gauge

$$= \left(\frac{V}{483}\right)^2 \times 4 \times \frac{\text{perimeter} \times \text{length of path}}{\text{area}} + \left(\frac{V}{66}\right)^2$$

the result is obtained thus:

$$\left(\frac{88\frac{1}{2}}{483}\right)^2 \times 4 \times \frac{6,280 \times 45}{62.8} + \left(\frac{88\frac{1}{2}}{66}\right)^2 = 618 + 1.8,$$

i.e. 620 inches of water.

It should be noted that V is in feet per second; the dimensions, giving a simple numerical ratio, may be in any unit. Even if we make all the allowances possible, viz. allow 30 degrees C. rise (reducing the head to 4/9ths its value) and assume the air blown in both ends of the centre and then out through the ventilating ducts (reducing the head a further  $\frac{1}{2}$ ) there is still a 68-in. head required, a figure which is absurd for a self-ventilated machine. I think these figures if considered, will, apart from the common-sense point of view, entirely disprove the possibility of getting enough air through a narrow induction-motor air-gap to get rid of such an appreciable quantity of heat as that mentioned. With regard to the heat dissipated from the ventilating ducts, I should like to know how the figure of 2,200 watts (page 251) was calculated, as I cannot reconstruct the calculation from Appendix VI. What was assumed to be the air velocity in the duct, and in general what is the velocity in a ventilating duct? It is certainly less than the peripheral speed of the machine, but how much less? Also, with regard to the heat dissipated from the back of the stator core, in most of the box-type frames in use the air driven out by the revolving rotor passes over the back of the stator laminations. Under these circumstances surely the heat dissipated must increase with the peripheral velocity of the machine, so that a formula of the type  $(1 + nV)$  would be expected to apply. While I agree that the machine considered should not get unduly hot, I submit that the method of calculating the watts dissipated leaves something to be desired.

Mr. J. FRITH: One is naturally disappointed that two such interesting points are left out of this paper, as the commu-

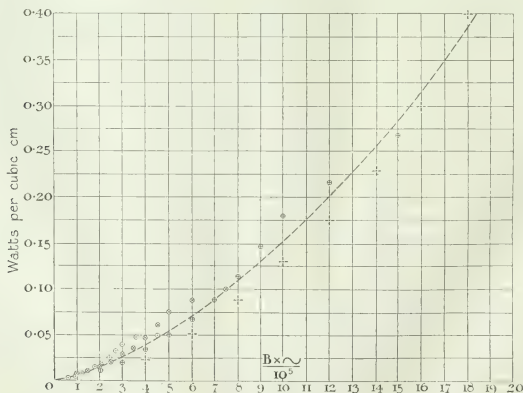


FIG. C.

b. tation of continuous-current machines and the predetermination of the regulation of alternators. Next, why do the two classes into which methods of design fall both refer to the flux-loading? Surely the current-loading is equally important, and the ratio of the two more so. The method of taking the maximum induction in the air space and multiplying it by the maximum possible air-space area to get a large and fictitious value for the flux may very likely improve with acquaintance; but one of the stated advantages, viz. that it does not necessitate working out the number of teeth carrying flux from one pole, seems to me to be a disadvantage. In connection with Mr. M. B. Field's work, I should prefer to see a reference to his Manchester paper\* instead of to his American paper. In the former are given most convenient curves for the calculation of the increase of ohmic resistance due to the forcing outwards of the current in the conductors in a slot by their own leakage flux. In the induction motor on page 249 why is the starting torque put down as 0.36 and the maximum torque as 2.7 times the normal? Surely a motor of this size would not be started without a rotor resistance. In the figure on page 257 I would most earnestly plead that the vectors should represent fluxes and not voltages, and that the problem be considered as a magnetic one. The line  $OE_F$  would be the stator flux,  $E_F, E_G$  the stator leakage flux, and  $OE_R$  the air-space flux. The rotor flux would be got by adding arithmetically the rotor leakage-flux to the air-space flux. The synthesis of the magnetizing current would then be worked out using these three fluxes. This method seems much more rational than translating fluxes into voltages, which in many cases have no physical existence at all. The same thing applies to the treatment of commutating poles. In the estimation of iron losses, the author does not consider the use of one combined curve in which watts per cubic cm. are plotted against the product of induction and frequency. One curve is then obtained which can be used for all frequencies and inductions, and which, considering the problematic nature of the evidence, might be sufficiently accurate. Such a curve is shown in Fig. C, plotted from those on page 263, taking points every 2,000 lines per square cm. from all the four curves given. In this connection the author might have said more on the connection of alternating and revolving magnetization, i.e. on the difference between the iron losses in continuous-current and alternating-current machines. This whole matter is one of which additional research work ought to be done.

in. Mr. G. A. JUHLIN: The paper covers such a great field that one can only touch very briefly upon some points. From personal experience, although it is comparatively short, I can say that the method outlined by the author makes the work of a busy designer easy, as it enables one to get a clear conception of the various factors involved. In some ways it has disadvantages, and for men with short experience they may be great, but once the method is clearly understood it proves exceedingly quick. With regard to the calculation of the induction-motor leakage, I do not think that the splitting up of the leakage into several different parts is a serious disadvantage. It certainly involves a considerable amount of work if a new line of motors has to be designed, but in such a case the labour would be justified. In a manufacturing firm,

machines are generally laid out on certain constant lines, Mr. Juhlin, and it is quite feasible to draw curves by the aid of which the different leakages—either the slot, zig-zag, or end leakage—can be calculated very rapidly. I should have liked to have seen in the paper some reference to belt leakage on induction motors, which may in some cases be of considerable importance, and in that connection I think a reference to the paper by Professor Adams before the Electrical Congress at St. Louis in 1904, and also to a paper before the American Institute of Electrical Engineers in 1905, will be of interest. There are some interesting points brought out with regard to the zig-zag leakage in the paper of 1905, and with regard to the belt leakage in the paper before the Electrical Congress. There is one apparent contradiction in the present paper. The author says it is hardly worth while to calculate the iron losses, or to attempt to calculate them very accurately, but at the same time one of the main points on page 245 is the determination of the temperature rise. It would seem, however, that without some fairly accurate idea of the iron losses it is not possible to make any estimate of the temperature rise. I would go further and say that it is necessary, or at least desirable, to calculate the losses in the different parts of the iron. I would also refer to the curves given on page 263. Taking the 50-cycle curve, the losses increase approximately as the square of the density. In most finished machines, with the high densities at which we work at the present time, the actual open-circuit losses increase frequently at the rate of the third or fourth power of the densities, so that it would seem that the curves give altogether too low values for the losses. It must, of course, be noticed that all the losses which we encounter in the finished machine do not by any means lie in the laminations, as already pointed out by the author. A great part of the losses will be found in the iron structure supporting the laminations, and probably a part may be found in the copper, especially in continuous-current machines with high tooth densities. In respect to the curves, I should like to repeat a question which has already been asked, namely, whether the curves refer to alternating or continuous-current machines. I think the losses are very much higher in continuous-current machines than those which one would calculate by the use of these curves. It would seem necessary to discriminate between losses in different classes of machines, as they vary within wide limits. The eddy-current losses increase very rapidly with the working of the iron, and to calculate losses accurately a factor, depending upon the surface which has been punched, should be introduced. In turbo-alternators, for example, the iron loss proper will closely approximate to the losses in transformers, as there is a large mass of iron which is not in any way worked; on the other hand, in induction motors where a large number of small slots may be used, the worked surface is considerable and the losses therefore high. The same remark would refer to the continuous-current machines. Tests carried out on transformers show considerable increase in losses due to machining of the joints, although the surface worked is a comparatively small part of the total. With reference to the formula for temperature rise given on page 264, I have found it give very good results for continuous-current armatures and also for alternator field-coils. The constant appears, however, to be somewhat low.

\* Journal I.E.E., vol. 37, p. 101, 1906.

Mr. Grime.

Mr. R. E. GRIME: There are many authors of textbooks on electrical engineering, and even on electrical design, who delight in long and abstruse investigations resulting in complicated formulæ, often difficult to apply in practice. Under present-day strenuous conditions, such investigations are of little use to an electrical designer in his everyday work, unless their results can be reduced to simple form and quickly and easily applied. This is only possible if the underlying physical phenomena are kept very clearly in mind throughout, and approximations made as required by limitations of shop accuracy and time available. Designers, therefore, owe a great debt of gratitude to the author, not merely for the results of long experience contained in his recently published work, and in the numerous and valuable papers he has given to the Institution, but still more for the clear physical insight into the conditions determining the behaviour of electrical machinery, which permeates all his work. I was therefore very much interested in the unified methods outlined by the author, as summarized by the design sheets on pages 250 and 251. If one may venture on a criticism of this sheet without having had practical experience of its use, it is that there is too much on it. For instance, a great deal of space is occupied with quantities which are only required for induction motors, and space limitations result in a number of contractions which are somewhat mysterious to the uninitiated. Would it not be possible, without sacrificing in any way the advantages of the method of calculation (and some of these are very obvious) to have a special sheet for each type of machine? Three such sheets would fulfil most purposes. The available space for figures and calculations would be much increased, and I think that the liability to error would be appreciably reduced. The author practically limits the paper to methods of calculation, as distinct from methods of design. In practice, the art of design is, of course, inevitably bound up with the processes of calculation, and it is difficult to separate the two things entirely. After reading the third paragraph on page 247 it is consoling to reflect that a designer's life is not by any means so monotonous as it would be if his work "merely consisted in filling in the proper figures in the appropriate places." The author's method gives prime importance to what may be described as the "frame constants," that is the idealized total magnetic flux crossing the air-gap,  $A_p B$ , and the total ampere-conductors  $I_a Z_a$ . I wish to enter a plea for the utility of the specific magnetic and electric loadings, especially in preliminary calculations. The specific magnetic loading is the average air-gap induction around the whole machine. Denoting this by  $B_{av}$ , its value is  $B_{av} = 2\phi/(2\pi r l)$ . The specific electric loading is the quantity  $(I_a Z_a)/(\text{circumference})$ , and is often denoted by  $q$ . These two quantities have the great advantage that for a given type of machine they remain as constant as most engineering constants usually do, over a wide range of frame sizes. In fact, it is by the variations which are found necessary in particular cases that their utility is accentuated, as they give just as clear a picture of the fight between copper and iron as do the total magnetic and electric loading of the frame. After some experience with them, a designer can usually estimate what values to aim at, and make these two quantities the basis of the first tentative design. The output coefficient given by the

$D^2 L$  formula on the design sheets always strikes me as Mr. C. being a rather blind way of estimating the use which is being made of the available space and material. This coefficient is inversely proportional to the product  $B_{av} \times q$ . For instance, in a continuous-current machine, after allowing for internal resistance drop, the  $D^2 L$  formula may be written

$$\frac{KW}{RPM} = D^2 L \times B_{av} \times q \times \frac{\pi}{6} \times 10^{-12}.$$

This expression is, or should be, familiar to every student, and I mention it merely to bring out the fact that whereas the ordinary output coefficient is often used to indicate that it is possible to put a given output into certain dimensions, if this coefficient is replaced by the two quantities,  $B_{av}$  and  $q$ , the designer can see at once how it is possible to get it into those dimensions. It is obvious that the maximum air-gap induction  $B$  may be used instead of the average value, at the discretion of the designer, as the author's field-form coefficient  $K_f$  is simply the ratio of these two quantities, namely,  $B_{av} = K_f B$ . As an example, in induction motors possessing a large number of poles, considerations of power factor often limit the magnetizing current to say 35 or 40 per cent of the full-load current. This percentage is directly controlled by the ratio of the specific magnetic to the specific electric loading, as shown by the following formula:—

$$\frac{I_m}{I_a} = 1.85 \frac{B}{q} \times \frac{g_{eff}}{\tau},$$

where  $I_m/I_a$  is the ratio of magnetizing current to full-load current,  $B$  is the maximum air-gap induction,  $q$  the specific electric loading  $I_a Z_a / (2\pi r l)$ ,  $\tau$  the pole-pitch in cm., and  $g_{eff}$  the air-gap length in cm., corrected for slot openings and with an additional allowance for iron. This simple relation is often of great service in the preliminary stages of design. With regard to temperature rises, the product  $q \Delta$  of specific electric loading by current density in armature copper often gives a very close idea of the temperature rise of standard machines. This product obviously does not take into account all the factors governing temperature rise, but it is something more than an empirical rule, for it is easily seen that it is proportional to the copper loss per square centimetre of air-gap area, and also in the case of a barrel winding, per square centimetre of end-connection cooling surface. Thus for a given continuous-current frame of practically constant flux a curve can be plotted showing the relation between the permissible value of the product  $q \Delta$  and the peripheral speed. There would be no great advantage in this were it not for the fact that over quite a wide range of frame sizes this curve remains practically the same. In a line of standard machines of one type, therefore, such a curve, when once determined, gives instantly a fairly close indication of the current density which must be employed in connection with any proposed value of the specific current loading. With regard to the iron-loss curves given in Fig. 11, I can confirm the remarks of other speakers that in completed machines the observed total iron loss is usually considerably higher than that indicated by the curves. This is particularly the case in continuous-current machines, even with laminated poles and with

roofed slots. In induction motors and alternators, at the flux densities usually employed the losses generally increase approximately as the square of the total flux, while in continuous-current machines the index is usually 2.5 to 2.8, or higher at very high tooth inductions. The author mentions one reason for this, but for the present the difficulties in the way of forming a reliable estimate of the extra losses are so great, especially in view of the large differences produced by small shop variations, that the allowance for them must remain mainly empirical.

The question of stray losses dependent on the load, although very important, has been little discussed in this country, and the author confines himself in the paper to

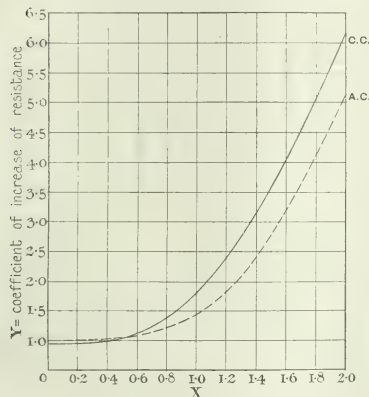


FIG. D.—Effective increase of resistance of embedded portion of standard 2-layer barrel winding, due to leakage field across slot.

$X = \pi r_1 \times \text{depth of conductor in cm.}$

$r_1 = \frac{\text{pitch} \times \text{width of conductor (bottom)}}{\text{width of slot}}$  for copper at 60°C.

$Y = \text{Coefficient of increase of resistance (mean of top and bottom conductors).}$

Curve C.C. is based on straight-line commutation, with total width of commutation zone equal to one-tenth the pole-pitch.

Curve A.C. is the mean of Field's curves for first and second conductors carrying sinusoidal alternating current.

the calculation of the eddy-current losses in the conductors embedded in the slots. It is therefore hoped that the following note on stray losses in continuous-current machines may form a starting point for further discussion and investigation. Those stray losses which are dependent on the load are mainly accounted for by (a) eddy-current losses in the conductors embedded in the slots, and (b) additional iron loss due to distortion of field-form by armature reaction. There are a number of other and more elusive losses, but in normal machines at normal loads these should be comparatively small. The effective

increase of resistance of embedded conductors carrying sinusoidal alternating currents is well known from the investigations of Messrs. A. B. and M. B. Field, referred to on page 248. No figures are easily available in this country, however, for the corresponding losses in the armature conductors of continuous-current machines. Owing to the almost rectangular shape of the current wave-form in the latter case, the effective increase of resistance is considerably greater than when the same conductor is carrying a sinusoidal alternating current. The curves shown in Fig. D may therefore be of some use as a step in the direction of increased accuracy. The lower curve, marked A.C., gives the mean coefficient of increase of resistance for the top and bottom conductors of an ordinary barrel winding carrying a sinusoidal current. The upper curve, marked C.C., shows the corresponding effect in a normal continuous-current winding. The effective resistance depends somewhat on the width of the commutating zone, being higher when narrow brushes are employed. Within the usual limits of practice, however, the difference is not comparatively very great, and the curve given is therefore based on the assumption that the effective total width of the commutating zone is one-tenth of the pole-pitch. It is calculated in the manner suggested by Mr. M. B. Field.\* It is unnecessary to give the details of the calculation, as this is merely a matter of tedious arithmetic. The eddy-current losses in an actual machine are dependent on the nature of the commutation. Straight-line commutation is here assumed, so that the current wave-form is a trapezium, and it is also assumed that all the conductors in one slot are being commutated simultaneously. The end connections, of course, are not appreciably affected by eddy currents of the nature considered here, and as it is usually necessary to make the armature conductor of uniform section throughout (except occasionally in turbo-generators) it will be found that there is very seldom much to be gained in total copper loss by making the top conductor smaller than the bottom one. For simplicity, therefore, the curves show only the mean increase in top and bottom conductors, assuming these to be identical in size. The stray iron losses on load are not so amenable to calculation, owing to the unsymmetrical and awkward shape of the field-form. It is possible, however, by ignoring the field-form altogether, and simply considering the maximum induction under the trailing pole-tip (of a generator), to arrive quickly at a result which is at least of the right order of magnitude. The method of procedure, then, is to calculate the actual maximum air-gap induction at the pole-tip due to the combined main and armature magnetizing forces available at this point, and read off directly from the no-load iron-loss curve the total iron loss corresponding to this air-gap induction. In spite of the crudeness of the method, it has given fairly good results, even for machines running with very weak main fields such as boosters and variable-speed motors. As an example of the accuracy to be usually expected, the following table summarizes the results of tests and calculations on two 900-kw. 230-volt 150-r.p.m. continuous-current generators, which were coupled together and tested by the Hopkinson parallel method. It will be seen that the results are somewhat

\* *Journal I.E.E.*, vol. 37, p. 83, 1909.

Mr. Grime on the safe side at half load, but on full load there is some stray loss still unaccounted for:—

Approx. load on generating machine ... ..	Full	3/4	1/2
Total armature losses in two machines calculated in ordinary way from measured resistances and observed no-load losses ...	kw.	122.4	88.0
Actual total losses from Hopkinson test ... ..	153.3	105.7	71.7
Difference (actual stray load losses) ... ..	30.9	17.7	8.6
Additional eddy-current copper losses from Fig. D ...	8.1	4.3	1.9
Additional iron losses calculated as outlined above ...	20.2	15.9	9.8
Losses still unaccounted for in two machines ... ..	+ 2.6	+ 1.8	— 3.1

Mr. Townend

Mr. R. TOWNEND: During the last 10 years I have used several methods of calculating the magnetic quantities of machines, and I have certainly found the method described by the author to be the most convenient. It is not always desirable to incorporate in one constant several values which may vary, yet the single constant  $K_m$  which takes into consideration several factors, is exceedingly useful. It is only necessary to know the values of  $K_m$ , the maximum flux density in the gap, and the number of ampere-turns

connected winding  $K_m$  is 0.389 with an infinite number of slots; 0.39 with 9 slots per pole; 0.395 with 6 slots per pole; and 0.41 with 3 slots per pole. It is interesting to note that with a sinusoidal field and an infinite number of slots,  $K_m$  is easily obtained as shown in Fig. E. The author thinks it advantageous to use one form of calculation sheet for different types of machines, and whilst the form illustrated in the paper certainly appears to be suitable for this purpose, I think it is far too crowded, and the spaces for the figures are much too small—assuming, of course, that the illustration is approximately full size. A different form of calculation sheet for each type of machine is, in my opinion, highly desirable, and materially assists in the prevention of mistakes. If a designer has been designing alternators for a considerable period, and should then be called upon to design continuous-current machines, a mistake is easily made in the tooth section if he forgets that in one case two-thirds of the tooth depth should be added to the armature diameter, and in the other case four-thirds of the tooth depth subtracted from the armature diameter (assuming that the density is being measured at a point one-third of the tooth depth from its narrowest part). I find that using a different form certainly assists in the prevention of such mistakes.

Mr. W. E. M. AYRES: Several points I would have mentioned have been already touched upon, but I will mention two or three matters where perhaps comment rather than criticism might be useful. For instance, in the calculation of the magnetizing current the author gives us a very good, useful, and quick way of getting the amount for the air-gap, and he refers us for the rest of the circuit to Dr. Smith's paper or Dr. Kloss's paper which, of course, are excellent methods but rather involved. I have found it very useful, particularly in the calculation of the magnetizing current on induction motors, to plot out curves for the magnetizing current in terms of the air-gap and to plot against flux densities for different parts of the magnetic circuit. It works out very well in practice. The author gives curves for the losses in iron, which curves, I believe, in common with others, are for alternating-current machinery, but I must say that I have not found actual losses to taper off to such an extent at high densities. There is another point which, as a practical designer, I have come across, but which the author does not mention. It often happens in certain types of induction motors, where it is necessary to have open slots in the stator, that if we calculate our iron losses from these curves our calculations will be a very long way out, since there are other losses which come in, due to the open slots. If we had infinitely thin iron and perfectly insulated sheets, there would not be any of these eddy currents in the rotor teeth due to pulsations set up by the open slots, but actual punchings have appreciable thickness and, due to working, are frequently burred so as to touch one another. There is another point also about the iron losses in induction motors. Taking the same curves for the losses in the teeth and in the core is frequently not accurate enough. As Mr. Jublin pointed out in his remarks, if the core is substantial, as it is in turbo-alternators, it is practically unworked iron, while round the slots is considerably worked iron. With a large

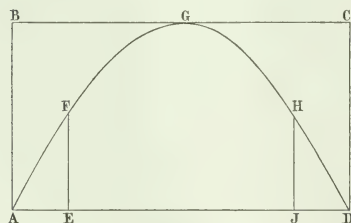


FIG. E.

Area EFGH  
 $K_m = \frac{\text{Area EFGH}}{\text{Arc AED} \times \text{D} \times \frac{\pi}{2}}$   
 A D = Pole-pitch.  
 E J = Width of phase band of conductors connected in series.  
 = 1.3 A D star-connected 3-phase winding  
 = 1.2 A D 2-phase winding  
 = A D single phase winding with all slots wound.

per inch periphery, to have a very good conception as to whether the frame under consideration is being used to its best advantage. Curves can be drawn giving the value of  $K_m$  for 3-phase machines for different ratios of pole-arc to pole-pitch, and air-gap at centre to air-gap at tip of pole.  $K_m$  for a 2-phase machine is obtained by multiplying the value of  $K_m$  for a 3-phase machine by  $\sqrt{2}/3$ . The number of slots per pole affects to a slight extent the value of  $K_m$ , but with the number of slots used commercially the variation is, however, negligible. For example, with a sinusoidal field and a 3-phase star-

number of induction motors, we have quite a small section of core and a large space taken up with slots. I find it is quite necessary, to get at reasonable results of sufficient accuracy for practical work, in some cases to take quite a different factor for the losses in the teeth compared with the losses in the core. To estimate closely the heating of machines, and particularly of induction motors, is a very complicated matter. The author gave a formula for the cooling in the air-gap, and Mr. Carr showed what that would mean in an induction motor where we have a very small air-gap. But if we have a rotor containing considerable losses, and which does not ventilate well, the air-gap, with the air rushing through it at high speed, is a very convenient way for the rotor losses to get to the stator. In many cases a reduction of the rotor losses has resulted in cooler stator iron, though the stator iron losses have been increased. Referring to the heating in the stator, with good ventilation the heating and the distribution of heat can be very considerably modified merely by taking away the heat more efficiently from the end connections. A previous speaker mentioned that the heating of the end connections can be very easily proportioned by taking the product of the current density in the windings by the ampere-wires per unit length. The product of those two, of course, is a comparative measure of the heating per unit area of the stator connections quite irrespective of the length of those connections. If we take those two figures divided by a function of the rotor speed, we get at the heating of the end connections very satisfactorily. I also agree with Mr. Grime in taking the ampere-wires per inch length, because that gives us values which we can easily remember, and is comparative from one machine to another. We do not have to remember a lot of figures for different classes of machines which have no common basis. Taking the figure of ampere-wires per unit length of periphery as the current loading, and air-gap flux density per unit area as the magnetic loading for any machine, the product of these two by  $D^2 L$  gives a measure of the output, and by a glance at those figures we know instinctively from experience how that machine is loaded.

Mr. H. VICKERS: The figures given by the author for the end-connection leakage of motors with barrel-wound and squirrel-cage rotors do not agree with those given by Gray and others, and are not confirmed by general experience. Gray states that the end-connection leakage of machines with barrel-wound rotors is about 35 per cent greater than that of machines with squirrel-cage rotors. The reverse of that is contained in the tables. I have found in actual practice that Gray's statement is in keeping with the facts. The calculation of the short-circuit current with different types of windings is a problem of great interest and importance to the designer, for upon it he judges the performance of the machine. Most methods which have been advocated for its estimation are little short of being useless in that they neglect many important factors. The author has given us information which enables us to predict with a certain measure of certainty what the short-circuit current will be. I refer to the leakage constants for the end connections with different types of windings more particularly. I do not agree with the author in neglecting the belt leakage. I take it that he draws no distinction between the zig-zag and belt leakages. To my mind that distinction cannot be too strongly

emphasized. For the benefit of those who have not studied Mr. Vickers the question, it may be well to point out that the zig-zag leakage is produced by the full ampere-conductors of the phase belt of both stator and rotor; whereas the belt leakage is produced by that component of the phase ampere-turns of the stator which is not neutralized by the rotor phase ampere-turns. Further, the paths of the lines of force produced are entirely different in the two cases. The belt leakage has been fully treated by Comfort A. Adams. It varies directly as the pole-pitch and inversely as the length of air-gap and the Carter coefficient, and is also dependent on the slots per pole and phase. The value of the zig-zag leakage calculated by the method given in the paper is excessive, and does not agree with the values deduced from theoretical considerations. I should like to know how the author calculates the effect of chording a winding on the short-circuit current, and the modification he makes on the constants for the end leakage in this case. Such windings are commonly used for obvious reasons, and it would be well to have definite information with regard to them. The method given by Dr. Kloss for determining the magnetizing current is much simpler than the method given by the author, and it is rather a pity it is not more widely understood. The iron-loss curves given by the author are much lower in value than those given by Gray and others, and obviously cannot apply to both alternating and continuous-current machines. It would be interesting to have some idea of the pulsating loss in the teeth of induction motors. These and many other points the paper and discussion do very little to solve.

Professor E. W. MARCHANT (*communicated*): This paper is very interesting to the electrical engineer who is not a designer, as an example of how rapidly generalization is proceeding in electrical engineering work. La Cour was, I believe, the first to suggest that testing of electrical machinery of all kinds might be done by a standard method involving primarily the determination of the magnetization curve and the short-circuit curve. The author has now gone one step further and has shown how all rotating electric machines can be designed on a uniform basis depending on the magnetic loading of the frame and on the current loading of the armature. It is interesting to note that this simplified procedure has been evolved from a consideration of the electromotive force in a conductor moving in a magnetic field. For a long time I have used that method for handling the theory of the dynamo, on the ground that it shows more plainly than any other the real mechanism of the electromagnetic machine. It has now shown its merits, the author points out, as a basis of design. The fact that no guarantee of regulation is generally given with high-speed turbo-generators, may possibly lead to trouble. A voltage regulator should, of course, take care of any excessive fall in pressure, but in some large stations where a great number of machines are nearly always running they have not been fitted. I came across an interesting example the other day of a temporary breakdown due to the bad pressure-regulation of a turbo-generator. In this case the turbo machine suddenly appeared to lose its voltage when working at about three-quarter full-load. It was driving induction motor-generators, and the most likely explanation of the stoppage appeared to be that the load on one of them momentarily increased, thus drawing more current from the mains and

Professor  
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lowering the voltage. This fall in voltage produced an increased demand for current from the other induction motors, with the result that the voltage fell right away and the overload releases opened. Of course, a pressure regulator might have saved the situation, had there been sufficient reserve excitation available, but a better regulation of the generator would have been still more effective as a safeguard against a pressure drop, though it would have involved a heavier overload on the turbine. I was very interested in the remarks about the losses in iron at high flux densities. Mr. McLachlan, working in my laboratory, found that the total loss could be represented up to  $B = 14,800$  to a high degree of accuracy by an expression of the form  $C B^n$ , where  $n$  was about 1.7 with "Stalloy" plates. It seems extraordinary that the total loss should increase so rapidly, at the higher flux densities, as was stated by several speakers in the discussion; possibly there may be some other loss which becomes noticeable, due to eddies in the conductors of the armature, when densities as high as 30,000 lines per sq. cm. are employed. With these densities at the roots of the teeth there must be a considerable flux through the slots, and this would of course, if the flux distribution were irregular, produce very heavy eddy-current losses, which would give the same result as increased iron loss on the measured loss of the machine. The author's remark about the amount of guesswork that a designer does, is hardly a complimentary way of explaining his position. I should prefer to say that successful guessing is an indication of the instinct of the designer, without which no designing engineer, however well versed he may be in technique, can hope to produce successful machines. A designer, even if he be a very scientific person, is, after all, an artist, and requires for success many of those qualities which the artist in painting and sculpture must have.

Professor  
Field.

Professor A. B. FIELD (*communicated*): In the opening paragraph of the paper the author anticipates much discussion of methods and forms of calculation as upheld by individual designers. Apart, however, from this, perhaps a note of caution should be sounded on a more general aspect of the subject that will arise in practice; and, as a corollary, an argument may be put forward for brevity and simplicity of the calculation sheet form, and for many blank spaces in it. Among the dangers of forms like these is the abuse of which they are susceptible. In the first place, when the forms or systems in vogue in an engineering office are elaborate, there is usually a tendency towards intolerance and a desire that every engineer in the department should conform with the system. This is partly appropriate in the case of the young engineers who have, so to say, been born and bred in those works; but beyond this, it is more conducive to a healthy development of the department to leave freedom of method, and to impose as little as possible any arbitrary systems of procedure. There is no necessary connection between the adoption of an elaborate form and these conditions arising; but, on the other hand, the matter will be found to work out that way in practice. Again, in the case of a machine which is largely new, and not merely a matter of changed winding or slight lengthening, or similar modification, the most lamentable results sometimes follow from filling in forms and obtaining a design to give certain pre-desired constants or apparent properties. It is so easy to be deceived

by mere figures and to juggle a design around until the tabulated result appears acceptable, that the comprehensive vision of the whole assembled machine, or of certain groups of proportions, is readily lost sight of. For this reason it is very desirable that in the case of completely new designs a certain amount of careful scale-sketching should be resorted to, and it then frequently becomes convenient to have many of the mechanical and electrical data entered upon such a sketch sheet, reducing the actual printed calculation sheet to its simplest possible form, as a labour-saver. There is the widest gulf between the mere diligent calculator and the engineer who has some designing genius. The latter will have a keen imagination, and will carry in his mind many features which have no pigeon-hole on the calculation sheet. He will generally be somewhat of an artist, and be able to draw, largely freehand, perfect sketches to scale of parts of the machine. In the case of the most accomplished designer I have known, the "calculation sheet" consisted of a page or two of a notebook carrying beautiful hand sketches and having a few important data entered. Other data, truly, might be worked out in more detail by an assistant, perhaps on a simple calculation or data sheet. Some of us have felt the personal handicap entailed by more or less lack of the above qualities, and have been driven to the development of some simple devices by way of compensation. The author is himself an accomplished artist with the paint-brush, and will doubtless agree that his designing achievements have been helped thereby, although, possibly, unconsciously more than otherwise. The main purposes served by a calculation sheet are for: (1) the careful designing of machines actually to be built, including the cases of (a) slight modification of existing machines, (b) machines almost entirely new; (2) estimating and similar work of a general or approximate nature; and (3) office records. Of these, (1a) and (2) will admittedly involve the filling in of very few items on the proposed calculation sheet; and (1b) is dealt with above. For office records a case may be made out for the proposed calculation sheet, but subject to the first objections raised. For this purpose, however, I believe it is much more useful to have a carefully prepared sheet or sheets giving the results of tests and the more important constructional or design data. Blue prints of these, filed for reference, together with a card index of the more important dimensions in easy tabular shape, form the office record.

Professor MILES WALKER (*in reply*): I do not agree with Mr. Carr that the calculation of the leakage of induction motors can be usefully reduced to the simple form which he suggests. The calculation, to be of any use to the designer, must contain at least the important factors which determine the result. The formulæ that I give are a compromise between the very elaborate formulæ given by some writers and the somewhat crude methods sometimes used by designers. The time taken to work out the short-circuit current by the method given in the paper is very short, and experience shows that the result is about as correct as one can hope to get from any method which does not take into account such complex factors as the saturation of the lips of the teeth. The suggestion made by some writers, that the iron loss on a continuous-current generator is greater than the iron loss on an alternating-current generator, is not in fact correct. A rotary

converter viewed from the slip-ring end is an alternating-current machine; it has identically the same loss as the continuous-current generator which one obtains by looking at the other end of the machine. It is true that if the designer of a continuous-current generator does not bevel his poles properly he may have very considerably higher losses in the teeth than would occur in an alternating-current generator in which the poles were properly bevelled. Moreover, open slots produce greater extraneous losses in the pole-shoes than semi-closed slots; but these are not true iron losses, and to include them in the iron-loss curve is to bring about that kind of confusion in which improvement of design becomes impossible. Fig. 11 was purposely reproduced because it differs so widely from figures given by previous writers; and the author is convinced that the true iron losses of dynamos, whether continuous or alternating current, must and do follow some such law as shown by the curves.\* It is impossible for the eddy-current losses in the iron to increase in a greater ratio than the square of the flux density. Where curves are obtained showing losses increasing at a greater ratio than this, it is because there are other losses, not true iron losses; and it is the business of the designer to ascertain where these losses occur and to allow for them independently. Several speakers have given useful methods for arriving at these extraneous losses. The great differences in the figures quoted by Mr. Carr show that there is something wrong in the method of using them. The extraneous losses of importance, which should be added to the legitimate iron loss, are:

- (1) Eddy currents in the copper conductors occurring at no load when the teeth become saturated.†
- (2) Losses occurring in the end-plates, owing to the flux bulging out sideways when the teeth are more highly saturated.
- (3) Pole-face losses.
- (4) Losses in the teeth owing to higher harmonics in the flux wave at no load, and especially at full load.‡

Mr. Carr's calculation, by which he arrives at a pressure of 620 inches of water in order to drive the air through the air-gap of the induction motor, is rather beside the mark, because it is a matter of common experience that the working face of an induction motor having an area of 14,400 sq. cm. can easily get rid of 4 kw. The reason is that the seven ventilating ducts are all providing cold air, which is rapidly intermixed with the air in the air-gap, there being 16 areas, each of more than 62 sq. cm., over which the mixing occurs, the mixing being done by the deeply-scored rotor surface moving at a velocity of 31 metres per second. The method of calculating the heat dissipated from the walls of the ventilating ducts is given on page 248.

In reply to Mr. Frith, reference is given on page 248 to both the papers quoted by him. The vectors  $O E_r$  and  $O E_o$  are given in volts for convenience in referring to the magnetization curve, Fig. 6. They are, of course, proportional to the corresponding flux vectors.

\* A member has sent me an iron loss curve taken from an induction motor which shows the inflection in a very marked degree. It confirms previous curves which I have seen. In fact, from the nature of things we shall always have the inflection if we deduct extraneous losses.

† "Das Nutzenfeld und die Wirbelstromverluste in massiver Armatur-Kupferleitern," *Sammlung elektrotechnischer Vorträge*, Stuttgart, 1903.

‡ F. W. CARTER: "Eddy-current Loss in Dynamo Teeth," *Electrician*, vol. 76, p. 369, 1915-16.

Replying to Mr. Juhlin, I do not say that it is not worth while to calculate the iron losses accurately, but that it is impossible to predetermine these accurately. I endorse what he says with reference to the extraneous losses occurring in addition to the legitimate iron losses.

Mr. Grime has entered into the true spirit of the discussion and given us a few methods of his own. I agree with Mr. Grime that it is, for some reasons, better to have a separate form for each type of machine. I have used one form in the paper in order to emphasize the possibility of treating the various classes of machines by the same general method of calculation. The specific electrical and magnetic loading referred to by Mr. Grime appear on the calculation sheet. The quantity  $q$  is given amongst the principal figures of the frame, under the heading  $(I_a Z_a)/(\text{circum.})$ . The reference to Fig. 11 is again made under the mistaken impression that this curve is intended to include extraneous losses, whereas it is intended to cover legitimate iron losses only. Mr. Grime's contribution to our method of estimating the stray losses in continuous-current generators is very valuable.

The graphic method given by Mr. R. Townend for finding  $K_r$  for a sinusoidal field-form is of interest.

In reply to Mr. Ayres, the calculation of the amount of air dissipated from the surface of the stator depends upon the temperature of the air in the air-gap, which is of course affected by the temperature of the rotor; so that the poorer cooling obtained when the rotor is hot is really provided for in the method of calculation. The ampere-wires per unit length of periphery are given on both calculation sheets in a prominent position.

I am afraid that the statement by Mr. Vickers, to the effect that the end-leakage of induction motors with barrel-wound rotors is 35 per cent greater than that of machines with squirrel-cage rotors, is completely wrong; the facts are quite the opposite. If both the rotor and stator are provided with a barrel winding, the two magnetomotive forces are opposed to one another, and the only path for the end-leakage lines lies in the narrow space between them. This makes the leakage for both the rotor and stator very much less than it would be if these magnetomotive forces were not defeating one another. In the squirrel-cage rotor, while the self-induction of the end-ring itself is not very great, the path of the magnetic lines from the stator winding is unobstructed, and experience shows that this results in a higher stator leakage. The right way for Mr. Vickers to criticize the method of calculating the leakage, is to give a more accurate method and show that his method is more correct by applying it to practical instances. Mr. Vickers himself told me that he has applied the method given in the paper of calculating leakage to a large number of induction motors, and that he finds by it he can obtain results within 10 per cent of the test figures. This is sufficient confirmation that the method is approximately correct. One cannot expect to get nearer than that unless we adapt the figures given in Table 2 to fit the particular dimensions of the winding used in each case. The method given in the paper includes belt leakage along with the zig-zag leakage. I do not agree that these can be distinguished from one another, except as different ways of looking at the same phenomenon. The matter can shortly be stated as follows:—In the stator we have certain slots in which lie

Professor Walker.

Professor  
Walker.

conductors exerting concentrated magnetomotive forces at definite intervals. In the rotor we may have a different spacing of slots in which lie conductors exerting concentrated magnetomotive forces of different values, which do not completely balance the stator magnetomotive forces from point to point. The magnetomotive forces in the stator and rotor, however, both conspire to produce a flux, the general direction of which is along the periphery. The cross-flux in practice is combined with the working flux, so that if we earmark any particular magnetic line we find that it does not go very far along the periphery before it is carried with the stream of the working flux into the body of the stator at one end, and into the body of the rotor at the other end. However, in order to speak more definitely about the leakage flux we must regard this flux along the periphery as it would exist if there were no working flux. Regarded from this point of view, its path is undoubtedly a zig-zag one, and this for two reasons: (1) because the easiest path lies backward and forward across the gap from stator to rotor teeth and vice versa, in dodging the openings of the slots; and (2) because the magnetomotive forces in the stator and rotor not being balanced at all points, the positive magnetomotive force at some points will completely overpower the negative magnetomotive force, and produce a flux which, from the point of view taken, may actually embrace some of the rotor conductors at one point and some of the stator conductors at another point. It is only by taking into account the exact distribution of the iron and air, the exact distribution of magnetomotive forces, and the number of conductors embraced by each zig-zag of the leakage flux, that one can arrive at a correct estimate of the effective electromotive force set up by the zig-zag leakage. Some authors content themselves with considering the effect of the distribution of magnetomotive forces, without taking into account the

varying reluctances of the paths (these authors generally lay emphasis on what they call "belt leakage"); while other authors content themselves with considering the magnetic conductivities of the path for the cross-flux set up by the magnetomotive forces in the stator and rotor. The latter procedure (especially if some allowance is made for want of balance of the magnetomotive forces) is found to give results sufficiently near for practical purposes. The thesis by Dr. Goldschmidt on the matter, quoted in the paper, gives in the author's opinion a method from which results can be obtained as accurately as one can expect in a matter so complex.

In reply to Professor Marchant, I think that the method of handling the theory of the dynamo to which he refers is also applicable to unipolar dynamos. In these machines the flux either revolves or remains stationary: if it remains stationary, then the conductors on the rotor cut across it; if it revolves, then it cuts across the stationary conductors in the frame. It is immaterial to the designer which it does. One of the best tests for finding whether an electromotive force will be produced in those very complicated machines which have been put forward by some inventors for avoiding commutators, is to ascertain whether one has got the flux so caught that it is bound to produce an electromotive force whichever it does. The results obtained by Mr. McLachlan are of great interest. It is to be hoped that he will be able to get results up to larger values of  $B$ .

I am in general agreement with the remarks made by Professor Field; but with all its drawbacks the calculation sheet serves many useful purposes. Not the least of these is that the data relating to a particular part are always entered in the same place on the sheet, so that they are found at a glance on a single sheet instead of by a hunt over several crowded pages of manuscript.

#### BIRMINGHAM LOCAL SECTION, 12 JANUARY, 1916.

Mr.  
Orsettich.

Mr. R. ORSETTICH: The value proposed by the author as magnetic loading of the machine is apt to bring about some misunderstanding to anyone who is not accustomed to work with this value continuously. The reason is that from its form it would appear to be a flux, whereas really it is a fictitious value of a flux which can never exist in the machine, and to obtain the real working flux it is necessary to take 30 per cent or 40 per cent of this value only. It would be impossible to compare the calculation sheets used by different designers in detail, and therefore the only way to bring about the discussion suggested by the author would be to quote points in which the design sheets proposed differ or are short of figures which one's experience shows are required in ordinary working. The purpose for which these sheets are used in manufacturing is, not only to have a ready reference, but also to have records of figures which are always comparable. To obtain this, it is necessary that different factors should be obtained by the same method, and as designers differ in their ways of calculating the various items, it is necessary that the design sheet should also contain the formulae by which these values are obtained. Current literature shows that different authors give widely different values for the same item, as, for instance, reactance voltage, coefficient of

cooling, and so on, and it would be impossible to compare machines designed by such different methods without introducing the probability of serious mistakes. In the design sheets as put forward there are a number of sections which do not require to be filled in for a particular machine, and it seems that the space taken up by these could be very conveniently filled by introducing the formulae by which the useful values are obtained. Another section which is extremely useful is one in which test results are entered and kept handy for reference whenever a similar machine is put through. Other items which are missed from the design sheets would be:—The size of the conductors after being insulated; particulars for ordering the regulators; arrangement and number of equalizers for continuous-current armatures and for rotary converters; leakage of the commutating poles; brush gear, and particulars of their loading and their losses; coefficient of cooling of totally enclosed machines; diagram or pitch of the armature windings; details of slip-rings and their loading in connection with rotary converters and large induction motors; method of starting rotary converters; control of the voltage of rotary converters. Dealing with the calculation of the field form of a turbo-generator, the very elaborate and interesting calculation explained in

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the paper seems to be mainly required on account of the design selected, which necessitates a square field being superposed upon a field which otherwise would be practically sinusoidal. It is also possible that the shape of the field resulting from this design may give rise to some troublesome harmonics in the shape of the wave. The tables of iron losses stated in the paper will be found extremely useful by most designers, especially in view of the extremely high densities up to which the curve is extended, densities which are never touched in the curves usually published. The diagram worked out by the author for calculating the leakage in the teeth of any type of machine is most useful and its method is entirely novel. It will be highly appreciated by all those who have to work out these values several times a day. The coefficient of cooling of coils and the calculation of the probable heating of the machine are based on previous papers published by the author, and have been duly acknowledged at the time. They represent a most valuable and original work on a field which has been hardly touched by other investigators, owing to the extreme difficulty of obtaining consistent results and also the fact that it necessitates large machines being at one's disposal for several months. Although the design of the turbo-generator is published only with a view to showing the method of calculating the several constants, one is tempted to say something regarding the design itself. The author seems to be satisfied that only a guarantee of temperature rise will be asked for in proposed machines, whereas in actual practice one finds that regulation guarantees are asked for, and these often extend to short-circuit figures both for sudden and permanent conditions, overload capacity for long periods, and so on. The most important question raised recently in connection with turbo machines is in connection with the use of embedded temperature detectors. The Engineering Standards Committee, in the last report (No. 72) recently published, mentions that whenever specified these detectors have to be taken as the correct method of measuring the temperature of such machines for outputs above 3,000 kw. Unfortunately, there is very little knowledge amongst manufacturers as to what these detectors really show, and what relations the figures obtained by detectors bear to the figures of temperature rise measured by the means available up to the present. The margin of 5 degrees allowed in the Report of the Engineering Standards Committee for temperatures taken with the detector appears to be extremely small. It is therefore extremely difficult to give guarantees based on this method of measuring the temperature, and it seems that this point should have been dealt with in the paper. Of the electrical features of the design shown, two points appear to be rather striking. The first is the high iron losses. I have measured accurately the iron losses on a 3,750-kw. generator running at 3,000 r.p.m. I found that these amounted to 52 kw. all included, and were obtained by running the machine as a synchronous motor from the mains. The second point is that the current density in the stator appears also to be higher than the figures usually adopted, but possibly with the system of ventilation adopted this might be permissible. Of the mechanical features, the high windage losses appear remarkable. On the machine above mentioned I have found the windage

loss to be not more than 55 kw. at full speed. This machine, however, was one with axial ventilation only, and with specially shaped fans. This seems to show that radial ventilation on high-speed rotors is connected with very high windage losses. On the other hand, the amount of air used for the ventilation of the machine appears to be small, and I would be inclined to assume 5.5 cubic metres rather than 4 for the particular design. In conclusion, the radial ventilation of the rotors with slots 9.5 mm. wide and 150 mm. deep appears to be extremely difficult to produce, as it can only be obtained by sawing the rotor across, which is a very slow and troublesome process. The axial ventilation of the rotor with 3.5-cm. holes right through the central portion appears to be also extremely difficult, because it would be impossible to bring the boring head anywhere near the point where the hole is started. If the design were one in which the shaft extensions at the two ends were made separate, this difficulty would be greatly reduced.

Dr. G. KAPP: With reference to the author's remarks Dr. Kapp. about the uncertain effect of radial ventilation discs, I should like to draw attention to the great difference in heat conductivity along and across the plane of the sheets. A careful investigation made by one of my students at the Birmingham University showed the conductivity in a direction parallel to the surface to be about 100 times greater than that across the sheets, the reason being, not only that part of the path lies in paper (a bad conductor), but also that at every change of medium, *i.e.* at every boundary between iron and paper, there is an abrupt drop in the temperature gradient. Given this great inequality in the two directions for the flow of internally generated heat, all of which has to leave the packet of plates on its outer boundary, equality of total temperature gradient between the central point and any point of the surface will be obtained if the ratio of width to thickness of packet is  $\sqrt{100} : \sqrt{1}$ , *i.e.* 10 : 1. To make the packets so narrow axially in comparison with their radial depth would obviously waste too much space for the ventilating ducts, and we find that designers prefer to introduce axial tunnels through the cores rather than to rely on the doubtful cooling effect of the flat surface of the packets. The edge surface within the tunnels and that of the armature circumference are far more effective. Some radial ventilating spaces are still retained, but I consider it to be a mistake to make those in the rotor and the stator register. They ought to be staggered, so that the air thrown out by the centrifugal action in the rotor is not projected into the opposing radial duct, where it can effect very little cooling. If the spaces are staggered, the air will have to flow axially until it reaches the next space in the stator, and it will thus take up heat from the edge surface of the stator. The formula mentioned in the paper for the temperature rise of dynamos gives fairly accurate figures in ordinary cases. It gives, however, too high a value if the air-gap is very small. My explanation is that with an air-gap of about 1 cm. a sort of envelope of warm air is, notwithstanding the centrifugal force, always carried more or less round with the rotor; more at low speed and less at high speed, and this condition is accounted for in my original formula where the divisor of the constant 333 is the product of the specific cooling surface and  $(1 + 0.1 \nu)$ . The formula was, however, found to be incorrect when

Dr. Kapp. applied to the armatures of my vibratory phase-advancer. In these machines the linear speed of the armature is very small and the term  $\sigma r v$  becomes almost negligible. When I first started designing this type of machine I was apprehensive lest the armature should heat too much, but I found that the temperature rise was far less than was indicated by my formula. Possibly the explanation is that with the very narrow air-gap employed (1 mm. or less) the envelope of warm air is continuously shaved off by the polar edges and fresh air permitted to reach the surface.

frame. The ratio of the magnetic loading to the current Mr. loading would also differ when for convenience the same frame is used both for a synchronous generator and for an asynchronous motor, due to the necessary change in magnetizing characteristics. The advantage of the author's calculation sheet over the methods in which the flux per pole is dealt with is not marked, since in this case also it is usual to employ as a guide the value either of the total armature-current turns per centimetre of the periphery, or the figure for this value corresponding to the particular

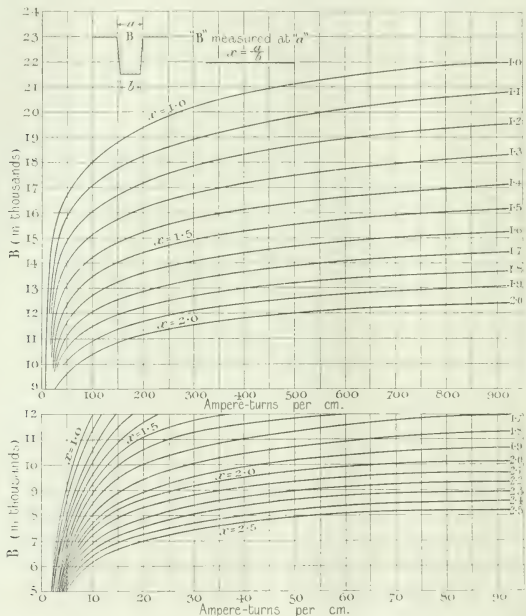


FIG. F.—Curves for iron parts of curved teeth.

Mr. Marden. Mr. W. MARDEN: As a designer I should like to record my gratitude to the author for this paper, since the information in regard to the methods of calculation adopted by other manufacturers is not usually offered for publication. The methods show originality over the usual textbook formulae, and the advantage of making the magnetic and current loading at once apparent can be recognized. Probably the more correct criterion for deciding if the thermal limit of the frame size has been reached would be the product of  $A_z B$  and  $I_a Z_m$ , a term proportional to the output per revolution, though this also would not be constant where a large range of speed is covered on the same

pole-pitch. It is to be noted that the author embodies on his sheet the actual ampere-turns per centimetre, as a suitable guide. Apart from this, the author's method suffers from the fact that his constant  $K_z$  is a combination of various factors, each of which can be separately influenced by changes of design. The fact that the actual value does not change largely for a given type—continuous-current generator, alternator, or asynchronous motor—is perhaps fortunate, but in my opinion it is better to keep well in view each of the separate factors that are subject to change, although it may only be necessary to consider the design in such detail for special cases. With this view,

Mr. Marden. a change from methods with which one is familiar cannot be justified, and one is more interested in the various

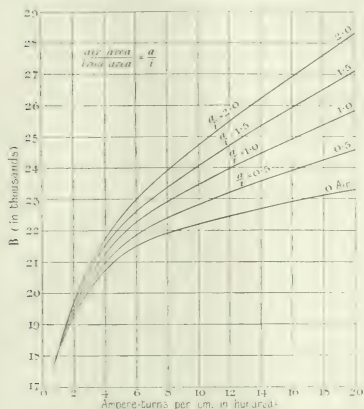


FIG. G.—Apparent values of  $B$  plotted against ampere-turns per cm. for varying values of "air area" to "iron area."

details of design covered by the Appendixes to the paper. In particular, the method of arriving at the correct magnetization for taper teeth appears somewhat com-

licated, and the curves used for this operation at the Stafford works of my firm for the past 10 years would probably be of interest, and the author's opinion on their reliability would be valued. In Fig. F each curve shows the ampere-turns per centimetre plotted against the minimum value of  $B$  for a section of given taper. The curve marked  $x=1$  is the ordinary magnetization curve, while that marked  $x=1.5$  is for a taper tooth in which the ratio of maximum to minimum area has this value. This secondary curve is derived by plotting the average value of the ampere-turns per centimetre over a range of  $B$  from 10,000 to 15,000, 12,000 to 18,000, 16,000 to 24,000, etc., against the minimum value of  $B$  in this series, and this average can of course be taken from the original  $B-H$  curves to any required degree of accuracy. The values from such curves will then hold good as the value of ampere-turns per centimetre, whatever the length of tooth in which the ratio of maximum to minimum area is represented by the value of  $x$ . When dealing with high tooth densities so that the parallel flux passing through the slots and vent spaces is of consequence, the curves are still used, but the ratio  $x$  is no longer the ratio of the areas at the root and tip of the tooth, but the ratio of the actual values of  $B$  at this point. The actual value of  $B$  is best obtained from the curves as shown in Fig. G, which are similar to those published by the author in Fig. 47 of his recent book.\* The actual value of  $B$  is found on the curve marked  $x=0$  on the same ordinate as that on which the apparent value of  $B$  occurs on the curve corresponding to the value of air over iron area for the section under consideration. The position of this ordinate can be judged sufficiently nearly by eye, when

\* "Specification and Design of Dynamo-electric Machinery."

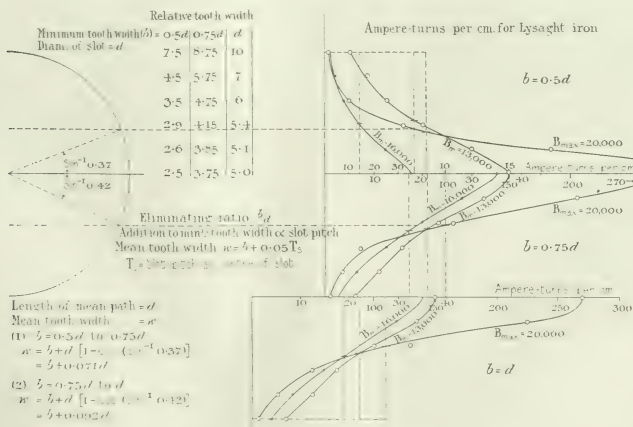


FIG. H.—Mean induction density with circular slots.

Mr. Marden. this ratio of air to iron section falls between two of the values for which curves are shown in this figure. Fig. H shows a method of deriving the mean value of  $B$  and the corresponding magnetization where slots of circular section are employed, and since it leads to the simple result that the effective width of the tooth, when taking that the tooth length equals the slot diameter, is given by adding 5 per cent of the slot pitch to the minimum tooth width, the curves may be of use to members as a short cut to the desired result of a reliable calculation.

Mr. R. G. JAKEMAN: In calculating the magnetizing current of induction motors as shown on page 249, the author advocates the use of the maximum flux density. It is well known, however, that if the field-form constant,  $K_f$ , is taken to be the same throughout, this method gives entirely wrong results if there is high saturation in the magnetic circuit. Hence it is necessary to take a different value of  $K_f$  (which is the ratio of the mean density to the maximum) according to the amount of saturation. It is my experience, however, that the method published by Dr. Kloss and Dr. Smith, which considers the density one-third of the way along the pole-pitch instead of in the middle, gives excellent results for the magnetizing current and is entirely independent of the saturation. In this connection also, in determining the flux density in the teeth of an alternator or continuous-current machine, the author tells us that it is not a simple matter to estimate the virtual number of teeth per pole if the total flux is taken as a basis. When the ideal flux,  $A_p B$ , is used, however, the factor  $K_f$  takes this question into account and has a different value for different bevellings of the poles. It seems to me that it is quite as easy to estimate the virtual number of teeth per pole as to estimate the value of  $K_f$ , since the latter cannot be worked out in each case. With regard to the calculation of the saturation curve of a turbo-alternator, on page 253, the author states that it is only necessary to consider the leakage flux in the end-caps when dealing with the polar projection, and not with the teeth. I find, however, that the leakage flux in the end-caps is practically constant for values of the ampere-turns per pole from 5,000 to 25,000, so that, referring to Fig. 4, the teeth within tooth No. 3 will all carry the same leakage flux density as the polar projection. I have shown in my recent article in the *Electrician*\* that it is quite simple to take this into account in calculating the magnetization curve. For the same reason, it is not quite

clear to me why the saturation curve on full load is Mr. Jaken's different from that on no load, as shown in Fig. 6. Since the leakage flux in the end-caps is practically constant, and the leakage through the slots and air-gap only occurs over a small space between the poles and is not a very large amount, I cannot see that the increased ampere-turns due to the armature reaction will have much effect on the total flux in the rotor. It seems to me to be a very difficult thing to determine the dotted curve in Fig. 6 experimentally, and I should like to know how it is done.

Professor MILES WALKER (in reply): I am in agreement with Mr. Orsetti in what he says as to the advantages of having separate calculation sheets for different kinds of machines. I have already stated my reasons for using one sheet, and on this one sheet it is difficult to include all the methods referred to by him. I also agree that it is important to have more work done upon the measurement of temperature by means of embedded temperature detectors. Very great care must be exercised in the fixing of the detectors if results of any value are to be obtained.

There is no doubt that when an air-gap is very small, the fact that the layers of air are shaved off in the manner described by Professor Kapp has a great influence upon the cooling of the rotor. Some machines have been provided with air scrapers, and these are quite efficient in producing better cooling.

The method of dealing with taper slots given by Mr. Marden is very simple and effective. The curves and data he gives are just the sort of contribution that I had hoped for in this discussion. I am glad to say that several members have given fresh data or described new methods of calculation. The total for the whole discussion makes quite a valuable addition to the data and methods previously published. This is a great contrast with the attitude of some critics who, without giving any better method which may be known to them, have instead exhibited a failure to understand and apply the methods given in the paper.

In reply to Mr. Jakeman, I know of no experimental method of determining the dotted curve in Fig. 6. In the paper it is intended to be calculated by adding to the ampere-turns at no load some extra ampere-turns lost in the iron parts due to increased leakage at full load. I think that the methods given by Mr. Jakeman for estimating the leakage are very useful, and that is why I referred to them in the footnote in the paper.

\* *Electrician*, vol. 75, p. 763, 1915.

## INSTITUTION NOTES.

## RESEARCH.

The Council have been informed by the Committee of the Privy Council for Scientific and Industrial Research that the following grants have been made to the Institution for one year's research work:

Heating of Buried Cables	...	...	£840
Properties of Insulating Oils	...	...	£250

The result of the application made by the Council in connection with seven other researches (see page 64) has not yet been made known.

## MEMBERS ON MILITARY SERVICE.

## (SIXTH LIST.)\*

MEMBERS.		
<i>Name.</i>	<i>Corps, etc.</i>	<i>Rank.</i>
Barber, C.	Royal Flying Corps	Lieutenant
Crompton, R. E., C.B.	Royal Engineers	Colonel
Crowe, P. B.	Lines of Communication	Colonel
Lonsdale, W. S.	Royal Engineers	2nd Lieut.
Michell, F. H.	South African Engineers	Lieutenant
Moore, E. E.	Anti-Aircraft Corps, R.N.A.S.	1st Class Petty Officer
Standford, W., D.S.O.	Cape Peninsula Convalescent Home	Colonel

## ASSOCIATE MEMBERS.

Anderson, A. M.	Royal Engineers	2nd Lieut.
Bailey, H.	2/4th East Lancashire Regt.	Captain
Ballard, L. W.	London Electrical Engineers, R.E.	Sapper
Barker, C. G.	Army Service Corps	Corporal
Barnard, J.	Army Ordnance Dept.	Lieutenant
Bennett, E. J. L.	Royal Field Artillery	2nd Lieut.
Berger, C. C.	Home Counties Divisional R.E.	2nd Lieut.
Caparn, E. T.	Royal Engineers	2nd Lieut.
Cornelius, V. A.	London Electrical Engineers, R.E.	2nd Corpl.
Davis, A. A.	South African Overseas Force	
Dollemore, R. S.	Army Service Corps	2nd Lieut.
Donkersley, N.	R.A.M.C.	Private
Emberton, F. T. C.	Royal Engineers	2nd Lieut.
Fulcher, E. W. P.	Royal Engineers	2nd Lieut.
Gaskins, F. W.	West Riding Divisional R.E.	2nd Lieut.
Hatch, W. A.	Royal Engineers	2nd Lieut.
Hunn, J. A.	R.N.V.R.	Lieutenant
Jacques, G.	Royal Flying Corps	2nd Lieut.
Keer, R. K.	London Electrical Engineers, R.E.	Sapper
Klitz, K. W.	Army Ordnance Dept.	Lieutenant
MacDonald, G. J.	Hampshire (Fortress) R.E.	2nd Lieut.
Montague, G.	Army Service Corps	Lieutenant

## ASSOCIATE MEMBERS—continued.

<i>Name.</i>	<i>Corps, etc.</i>	<i>Rank.</i>
Overton, T. R.	4th Maori Contingent	2nd Lieut.
Pattman, J. H.	Royal Naval Air Service	Petty Officer
Raven, N. V.	Inspection Staff	Assistant Inspector
Rice, R. K.	Royal Navy	Captain
Ross, J. D.	London Electrical Engineers, R.E.	2nd Lieut.
Saunders, F. E.	Royal Engineers	2nd Lieut.
Smith, A. J.	Royal Navy	Electrical Fitter
Smith, R. M.	Royal Engineers	2nd Lieut.
Strange, J. P.	London Electrical Engineers, R.E.	Sergeant
Stuart, C. E.	Royal Flying Corps	1st Class Air Mechanic
Timmis, A. C.	Royal Engineers	Lieutenant
Udall, R. O.	2nd Canadian Pioneer Battalion	Private
Wells, N.	R.N.V.R.	Sub-Lieut.

## ASSOCIATE.

Tucker, W. S.	London Electrical Engineers, R.E.
---------------	-----------------------------------

## STUDENTS.

Braathen, E.	Royal Flying Corps	2nd Class Air Mechanic
Castle, J. P.	3/2nd London Divisional R.E.	Lieutenant
Charles, D. S.	Artists' Rifles, O.T.C.	Private
Collyer, G.	London Electrical Engineers, R.E.	Sapper
Farmer, C. D.	London University O.T.C.	Cadet
Harrison, A.	R.N.V.R.	Electrical Artificer
Jones, L. J.	Royal Flying Corps	2nd Class Air Mechanic
McKenzie, H. J.	Royal Flying Corps	2nd Lieut.
Palmer, W.	Artists' Rifles, O.T.C.	Private
Partridge, D. G. B.	London Electrical Engineers, R.E.	Sapper
Ripley, H. S.	Tyne Electrical Engineers, R.E.	2nd Lieut.
Rogers, W. L. A.	London Electrical Engineers, R.E.	Sapper
Ross, G. M.	Royal Engineers	2nd Lieut.
Ryan, T. M.	Royal Engineers	Lieutenant
Scott, G. J.	4th Artillery Training School (T.F.)	Lieutenant
Simmonds, D. H.	Royal Naval Air Service	2nd Class Air Mechanic
Smethurst, F.	1/8th Essex Regt.	Lance-Corpl.
Topham, F. C.	R.N.V.R.	Sub-Lieut.
Walker, J. S.	Army Service Corps	Lance-Corpl.
Wenger, T. L.	Artists' Rifles, O.T.C.	Private
Whitney, J. S.	Royal Engineers	Corporal
Workman, E. W.	London Electrical Engineers, R.E.	Sapper

\* See vol. 53, pp. 199, 329, 388, and 857; and vol. 54, pp. 121 and 307.

PROMOTIONS, TRANSFERS, ETC., OF MEMBERS  
ON MILITARY SERVICE.

## (SECOND LIST.)\*

<i>Name.</i>	<i>Members.</i>	<i>Rank.</i>
Alkin, R. L.	4th East Lancashire Regt.	Captain
Bell, H.	1/3rd Northumbrian R.E.	Major
Caldwell, J.	3/6th Argyll & Sutherland Highlanders	Lieutenant
Morcom, R. K.	Divisional Engineers, R.N.D.	Captain
Sparks, H. C.	London Scottish	Captain
Stafford, C. S.	Canadian A.S.C.	Major
Wallis, T. M. W.	R.N.V.R.	Lieutenant
ASSOCIATE MEMBERS.		
Alderson, A. R.	Royal Engineers	Lieutenant
Allingham, G. C.	Divisional Engineers, R.N.D.	Sergeant
Boissier, E. G.	Royal Naval Division	Lieut. Com.
Brown, W.	Royal Engineers	Lieutenant
Davis, V. O.	Royal Engineers	Lieutenant
Dillon, T. F.	Royal Engineers	2nd Lieut.
Dutch, E. J.	14th Royal Fusiliers	2nd Lieut.
Dyke, G. B.	Royal Garrison Artillery	Lieutenant
Harrop, D.	12th Loyal North Lancashire Regt.	2nd Lieut.
Higgins, C.	London Divisional R.E.	Captain
Huddart, A. H.	Army Service Corps	Captain
Jackson, L. E. S.	2nd London Brigade, R.F.A.	2nd Lieut.
Layton, A. B.	South Lancashire Regt.	Lieut.-Col.
Mohr, S. M.	12th Notts & Derby Regt.	Captain
Nelson, G. D.	Royal Naval Air Service	Warrant Officer
Newton, R. S.	East Lancashire R.E.	Lieutenant
Roseveare, L.	Royal Garrison Artillery	Lieutenant
Salt, C. W.	London Electrical Engineers, R.E.	Lance-Corpl.
Summers, L. F.	Army Service Corps	2nd Lieut.
Symmes, H. C.	2nd South African Infantry	Captain
Wallis, T. S.	Royal Engineers	2nd Lieut.
Walton, W. H.	R.N.V.R.	Lieutenant
Watson, A. G.	R.N.V.R.	Lieutenant
Utting, S.	Army Service Corps	Captain

## ASSOCIATES.

Marco, P. H.	13th York & Lancaster Regt.	Captain
Wells, C. G.	Royal Engineers	Lieutenant

## STUDENTS.

Abbott, J. R.	Tyne Electrical Engineers, R.E.	Lieutenant
Angus, T. C.	Royal Naval Air Service	Flight Sub-Lieut.
Birch, E. E.	Royal Naval Reserve	Eng. Lieut.
Coombs, C. S.	6th Royal West Kent Regt.	2nd Lieut.
Deedes, J. G.	London Signal Service, R.E.	Lieutenant
Dobie, P.	Royal Engineers	2nd Lieut.

\* See page 307.

## STUDENTS—continued.

<i>Name.</i>	<i>Corps, etc.</i>	<i>Rank.</i>
England, M. O. F.	Royal Naval Air Service	Sub-Lieut.
Ferranti, B. Z. de	Royal Garrison Artillery	Lieutenant
Fruhe-Sutcliffe, R.	East Lancashire Divisional R.E.	Lieutenant
Goodswain, D. C.	2nd London Divisional R.E.	Lieutenant
Gripper, L. A.	British Red Cross	Driver
Harrison, R. W.	London Electrical Engineers, R.E.	Lance-Corpl.
Hedgcock, A. D.	London Electrical Engineers, R.E.	2nd Lieut.
Hellaby, J. A. B.	Royal Engineers	Lieutenant
Killingback, S. G.	London Divisional R.E.	Lieutenant
McMahon, V. H. M.	Army Service Corps	2nd Class Warrant Officer
Marston, G. S.	Royal Engineers	Lieutenant
Miller, N. H.	Royal Engineers	Sergeant
Morris, C. I.	12th Royal Warwickshire Regt.	2nd Lieut.
Norburn, W. H.	Hampshire (Fortress) R.E.	2nd Lieut.
Peter, L. H.	Cornwall (Fortress) R.E.	Lieutenant
Protheroe, R. N. L.	Royal Field Artillery	Lieutenant
Pryce, S. E. T.	Royal Garrison Artillery	Lieutenant
Tolley, C. E.	3/1st Northumbrian Divisional R.E.	2nd Lieut.
Wells, R. I.	3rd South Staffordshire Regt.	2nd Lieut.
Williams, C. S.	Divisional Engineers, R.N.D.	Corporal

## EXPULSION OF ENEMY MEMBERS.

As soon as the approval of the Board of Trade is obtained, the Council propose to call a Special General Meeting of the Corporate Members to consider and, if approved, to adopt the following addition to the Articles of Association:—

*Addition to Article 41: (a) In the event of a state of war arising between Great Britain and any other Country or State, any member of any class who at any time during such war shall be a subject of such enemy Country or State shall forthwith cease to be a member of the Institution, and in the case of the European War of 1914 all such members shall cease to be members of the Institution on and after .....*

(The date to be inserted will depend on the date of confirming the Resolution.)

The Council have also received a petition signed by 17 Corporate Members in regard to the expulsion of enemy aliens, asking that in accordance with Article 80, the Council call a Special General Meeting for the purpose of dealing with the matter. It is understood that the signatories are of opinion that the alteration proposed by the Council will effect the object of the petition.

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No. 257.

## THE SEVENTH KELVIN LECTURE.

### LORD KELVIN AND TERRESTRIAL MAGNETISM.

By C. CHREE, Sc.D., LL.D., F.R.S.

(Lecture delivered 17 February, 1915.)

In selecting a subject for a Kelvin lecture one naturally thinks of those branches of knowledge with which Lord Kelvin's name was most intimately associated. To a superintendent of Kew Observatory the subject which is specially associated with the name of Kelvin is atmospheric electricity. It is 53 years since the Kelvin "water-dropping" electrograph—the first it is believed of its kind—was erected at Kew under Lord Kelvin's personal supervision, and with minor modifications it has remained in use up to the present day. A Kelvin lecture upon Atmospheric Electricity was, however, delivered only two years ago by a distinguished authority, Sir Oliver Lodge,\* and I have accordingly selected for my subject to-night Terrestrial Magnetism.

Like most branches of physics, terrestrial magnetism has associations with the name of Kelvin, and, characteristically enough, these associations are at the two confines of the subject, the immediately practical, and the speculative. When a magnetician has administered to him the blunt question of what earthly practical use he is, his first protestation is that the observations which he takes are indispensable for the construction of Admiralty charts, and so for the navigation of the seas. Even this line of defence will be denied him if the gyroscope compass—one of the topics of last year's lecture†—comes to monopolize the field. Lord Kelvin, I need hardly remind you, introduced important changes of design into compasses, and the construction of compasses was an important object of the Glasgow firm which eventually bore his name. I do not propose to-night to say anything about the history of compasses, though it is a fascinating subject, as will be readily appreciated by anyone who consults the works of one of your past presidents, Professor Silvanus P. Thompson, and of Captain Schück. But I shall have a good deal to say about magnetic declination, a knowledge of whose

vagaries is an essential preliminary to the use of the compass. One of my objects to-night is to make clear the dependence in this connection of the practical man upon the scientific observer.

The other point of contact between Lord Kelvin and terrestrial magnetism, as already mentioned, relates to theory. All here know that there occur from time to time phenomena known as magnetic storms, during which there are difficulties in carrying on ordinary telegraphy. The way of overcoming these difficulties is what no doubt most immediately concerns electricians, but you will readily understand that the cause of magnetic storms is a matter of great interest to magneticians. There has long been a belief that the sun is the principal if not the only source of magnetic storms, and of the less striking regular changes every day visible. Lord Kelvin called attention to the difficulties in the way of accepting any sensible direct magnetic action between the sun and the earth. His earliest remarks on the subject, to which I shall refer, are contained in a short note on page 154 of volume 4 of his "Mathematical and Physical Papers." This appeared originally as a note attached to a paper in the *Philosophical Transactions*\* by Mr. C. Chambers, once on the staff of Kew Observatory and subsequently director of the Government Observatory, Bombay. Mr. Chambers sought to demonstrate that the well-known diurnal variation of terrestrial magnetism at the earth's surface does not arise from direct magnetic action of the sun, but in some indirect way, a view which no one to-day probably contests. Lord Kelvin evidently thought that the conclusion could be reached by simpler considerations than those advanced by Mr. Chambers. "If the sun," he said, "were a magnet as intense on the average as the earth, the magnetic force it would exert at a distance equal to the earth's . . . would be only 1/8,000,000 of the earth's surface magnetic force in the corresponding position relative to its

\* *Journal I.E.E.*, vol. 52, p. 333, 1914.

† *Ibid.*, vol. 53, p. 277, 1915.

\* Vol. 153, p. 515, 1863.

magnetic axis . . . the effect of reversing the sun's magnetization would be to introduce . . . a disturbing force equal to about 1/8,000,000 of the earth's average polar force, and would therefore be absolutely insensible. . . . The sun's magnetization would . . . need to be 120 times as intense as the earth's to produce a disturbance of 1' in declination even by a complete reversal in the most favourable circumstances."

It is interesting to note that in 1863 Lord Kelvin thought it reasonable to suppose that if the sun were a magnet the intensity of its magnetization would be of the same order as that of the earth. In the much later communication, to which I next refer, he displays an alteration of opinion on this point. This second communication was made in 1892 to the Royal Society,\* on an occasion—a presidential address—when original contributions to science are unusual. Lord Kelvin, however, devoted fully half his address to terrestrial magnetism. Referring in the first place to the problem he had considered 29 years before, he remarks that if the sun is to produce by direct action simply as a magnet a disturbance sensible to observatory magnetographs it "must be a magnet of not much short of 12,000† times the average intensity of the terrestrial magnet." Proceeding, he says (*loc. cit.*, p. 304), "Considering probabilities and possibilities . . . I find it unimaginable but that terrestrial magnetism is due to the greatness and the rotation of the earth. . . . It seems probable, also, that the sun, because of its great mass and its rotation, . . . is a magnet. . . . As the sun's equatorial surface velocity is nearly four and a half times the earth's, it seems probable that the average solar magnetic moment exceeds the terrestrial considerably more than according to the proportion of bulk. . . . We cannot say that the sun might not be 1,000, or 10,000, or 100,000 times as intense a magnet as the earth." It is interesting to observe that in 1892 Lord Kelvin was inclined to subscribe to the view which several eminent physicists, e.g. Professor Schuster, have thrown out as a suggestion, that the rotation of a large body may in some way constitute it a magnet. Holding these modified views, he regarded it as "a perfectly proper object for investigation . . . whether there is, or is not, any disturbance of terrestrial magnetism such as might be produced by a constant magnet in the sun's place with its magnetic axis coincident with the sun's axis of rotation," and he suggested that "the photographic curves . . . given by each observatory should be analysed for the simple harmonic constituent of annual period and the simple harmonic constituent of period equal to the sidereal day."

This seems to some extent a retirement from the position he took up in 1863, but he goes on to say (*loc. cit.*, pp. 305, 306): "Even if, what does not seem very probable, we are to be led by the analysis to believe that magnetic force of the sun is directly perceptible here on the earth, we are quite certain that this steady force is vastly less in amount than the abruptly varying force which, from the time of my ancestor in the presidential chair, Sir Edward Sabine's discovery, 40 years ago, of an apparent connection between sunspots and terrestrial magnetic storms, we have been

almost compelled to attribute to disturbing action of some kind at the sun's surface. . . ." After referring to various solar and terrestrial magnetic phenomena he adds (*loc. cit.*, p. 307): "But now let us consider . . . the work which must be done at the sun to produce a terrestrial magnetic storm." He then quotes from a paper by the late Professor W. G. Adams data relating to a magnetic storm of 25th June, 1885, and proceeds: "To produce such changes as these by any possible dynamical action within the sun, or in his atmosphere, the agent must have worked at something like 160 million million million million horse-power. . . . Thus, in this eight hours of a not very severe magnetic storm, as much work must have been done by the sun in sending magnetic waves out in all directions through space as he actually does in four months of his regular heat and light. This result, it seems to me, is absolutely conclusive against the supposition that terrestrial magnetic storms are due to magnetic action of the sun; or to any kind of dynamical action taking place within the sun, or in connection with hurricanes in his atmosphere, or anywhere near the sun outside. It seems as if we may also be forced to conclude that the supposed connection between magnetic storms and sunspots is unreal, and that the seeming agreement between the periods has been a mere coincidence. We are certainly far from having any reasonable explanation of any of the magnetic phenomena of the earth; whether the fact that the earth is a magnet; that its magnetism changes vastly, as it does from century to century; that it has somewhat regular and periodic . . . solar diurnal . . . variations; and (as marvellous as the secular variation) that it is subject to magnetic storms. The more marvellous, and, for the present inexplicable, all these subjects are, the more exciting becomes the pursuit of investigations which must, sooner or later, reward those who persevere in the work."

Lord Kelvin undoubtedly did useful service in calling attention to the question of the expenditure of energy in magnetic storms. It will, I think, be generally conceded that any such expenditure as his estimate gave, for what was really a comparatively second-rate storm, is wildly improbable; but it must be acknowledged that his estimate has little bearing on the theories of solar action mainly current to-day. Arrhenius, Birkeland, and Störmer, for instance, while regarding the sun as ultimately responsible for magnetic storms, believe the immediate cause to be something bearing an electric charge, originally projected from the sun, but present in the earth's atmosphere. Some at least of the earlier magneticsians, e.g. Balfour Stewart, would not, I think, have accepted the mathematical problem dealt with by Kelvin as corresponding with their physical ideas; but the fact remains that the positive experimental knowledge required to justify theories of a different type, such as Birkeland's, came into existence only towards the close of last century.

That destructive criticisms made by the president of the Royal Society, from his presidential chair, should have considerably lost their point in so short a period must somewhat encourage theorists who go ahead of ascertained facts, and some may even suggest that the criticisms retarded the advance of knowledge. To this view, however, I do not myself subscribe. When immediate action is necessary, reaching the right result by wrong or inconclusive reasoning—for instance, catching the right train because it started

\* *Proceedings of the Royal Society*, vol. 52, p. 300, 1892-3.

† Lord Kelvin must, I think, have had in view something larger than the least change detectable by magnetographs, possibly the ordinary range of the diurnal variation.

from other than its usual platform—may have advantages; but theories which are not in harmony with the physical knowledge of the day, even if correct, are only likely to lead to confusion until the apparent inconsistencies have been investigated and removed.

To-night I shall confine myself to three of the outstanding problems enumerated by Lord Kelvin: the secular change, the solar diurnal variation, and the phenomena of magnetic disturbances.

#### SECULAR CHANGE.

Taking first the secular change, the fact that the direction in which the compass needle points at a particular place is not invariable was not recognized until the beginning of the seventeenth century, a surprising fact considering that the compass had long been in use at sea. The late date of the discovery is doubtless partly due to imperfections in early instruments, and the consequent natural

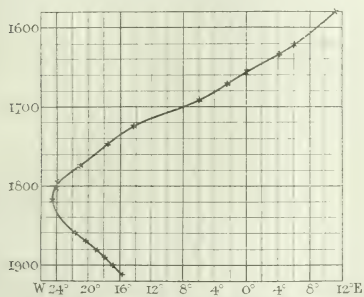


FIG. 1.—Changes of Magnetic Declination at London since 1580.

tendency to regard apparent changes as instrumental, but probably more to the prevalence of a priori philosophical conceptions.

The measurement of direction, whether of the compass or of the dipping needle, presented less difficulty than the absolute measurement of force. In fact, until the time of Gauss, the measurement of magnetic force was at too elementary a stage to render possible secular change measurements. Thus our knowledge of secular change prior to the nineteenth century is confined to declination and dip. For these elements we have in some districts data covering more than three centuries. Figs. 1 to 4 show graphically the changes that have taken place in London; but the earlier data cannot claim any very high accuracy. Not only were the instruments inferior, but the place of observation varied, and in the absence of magnetographs no allowance could be made for magnetic disturbance or diurnal variation. If we remember that declination at Kew exceeds that at Greenwich by fully 20', we can appreciate that "London" is somewhat a vague term magnetically.

The total range of *D* (declination) observed in London, as shown by Fig. 1, has exceeded 35°. The only actual

turning point observed, 24°6' W., presented itself about 1580, the direction of secular change then altering from westerly to easterly. We have no idea how the value 11°½' E. observed in 1580 stood to the previous turning point. The declination was approximately the same as at present in 1730. When, if ever, it will have the same value again, we have not the ghost of an idea. The change in each of the centuries 1600 to 1700 and 1700 to 1800 was about 16°, whereas during the last hundred years the change has been only about 9°. The rate of change has, however, markedly increased of late years, as may be recognized on consulting Fig. 2, which shows the change at Kew during the last 50 years on a much opener time scale than Fig. 1.

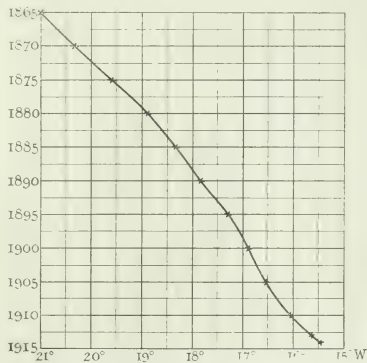


FIG. 2.—Changes of Westerly Declination at Kew since 1865.  
Change in last 50 years 5° 2'. Present Annual Change about 4'.

The turning point in the dip, when it attained its highest value (see Fig. 3), presented itself about 1723, or nearly a century before the turning point in *D*. The dip in London is now lower than it has been since observations began. Of late years the rate of change has been very small, but whether this heralds the near approach of a minimum, or is merely a temporary slackening, we do not know.

The fact that the magnetic elements vary would enable time to be indicated by the value of one of the elements at a fixed place. Instead of speaking, for instance, of the era of Oliver Cromwell, we might speak of the era when declination in London was from 0° to 1° W. But if we confined ourselves to one of the elements, there would obviously be ambiguities. The era of 20° W. declination might refer to 1765 or to 1872. By drawing a curve such as Fig. 4 in which declination is the abscissa, and dip the ordinate, we can represent past time unambiguously, but ambiguity might arise in the future. The curve shown in Fig. 4 may, in fact, be part of a closed curve, or of a loop. If it is part of a closed curve, we may feel reasonably certain that the completion of the cycle is still far in the future. While secular change has followed pretty much the same course at places so near together as London and

Paris, it is far otherwise with remote places. In 1608 the declination needle when first observed at Cape Town pointed east of north and was moving to the west as in London, but the westerly movement continued for 50 years after the reversal in London. In 1900 at Boston on the Atlantic coast of America the needle was moving about  $3\frac{1}{2}$  per annum to the west, whereas at Seattle on the

to unscientific circles, against theories which associate phenomena on the earth with sunspots. Ordinary observation suffices to tell us that if the supply of heat we receive from the sun is influenced by the greater or less prevalence of sunspots, the effect wants looking for. Thus any theory which claims that any terrestrial phenomena whatever are profoundly influenced by sunspots, naturally meets with

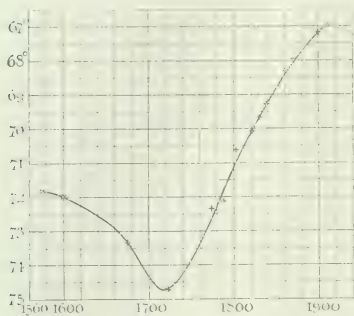


FIG. 3.—Changes of Magnetic Inclination (Dip) at London since 1570.

Pacific coast the annual movement was about  $2'$  to the east. Anything like a complete knowledge of secular change over the earth calls for extensive and systematic observation.

Various theories have been propounded as to the cause of secular change. One of the least startling associates it with underground changes of temperature. The magnetic properties of iron are largely dependent on temperature, and there may be much iron in the earth's interior; but, if the temperature increases with the depth at the rate ordinarily supposed, the fact that the earth's magnetism is so large as it is becomes rather a puzzle.

TABLE I.

Dr. E. Leyst's Original Data for Secular Change.

Station	Sunspot Maximum	Sunspot Minimum
Pavlovsk ...	$-5^{\circ}02$	$-3^{\circ}87$
Potsdam ...	$-5^{\circ}14$	$-4^{\circ}12$
Greenwich ...	$-6^{\circ}05$	$-3^{\circ}10$

From a study of the observed secular change at several stations, including Greenwich, and the leading Russian and German observatories, Pavlovsk and Potsdam, Professor Leyst of Moscow—a prolific writer on our subject—propounded the theory some years ago that secular change of declination is more rapid in years of many than in years of few sunspots. There is a certain prejudice, not confined

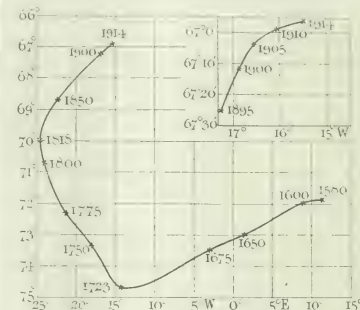


FIG. 4.—Secular Change at London in Declination and Inclination.

scepticism. There are, however, to-day few, if any, magneticians who deny that the amplitude of the regular diurnal variation of terrestrial magnetism varies *pari passu* with the number and area of spots on the sun. The spots, of course, may be only a symptom of activities on the sun to which the phenomena on the earth are due. Thus the theory of Leyst, though on general grounds it seems to me improbable, should not be condemned without due investigation. Tables 1 and 2 are intended to represent the arguments adduced by Professor Leyst in favour of it, and those adduced against it by myself. The data are mostly from groups of three successive years taken alternately at sunspot maximum and minimum, the intermediate years in the so-called 11-year period being left out of account. What may be described as sunspot minimum extends sometimes over more than three years. The years actually included in Table 1 are not clearly indicated in the original, but they seem to lie between 1890 and 1910. The Greenwich data, in particular, support the theory. It is never safe, however, to draw conclusions from a small number of years, as much may be due to accident. In Table 2 I have confined myself to Kew data, as I know that no instrumental or other changes have occurred there which could prejudice the conclusions, but the results would have been much the same if I had taken a mean from the observatories of Britain, France, and the Netherlands.

The first set of data in Table 2 are derived from the epoch 1892 to 1908, including two periods of three years of many sunspots, and six intermediate consecutive years of few sunspots. The period is much the same as Leyst's and the results fairly similar. The second essay dealt with the much longer period 1860 to 1908, from which

I derived five sets of three successive years of many, and four sets of three successive years of few sunspots. The mean results from the sunspot maximum and minimum years proved nearly equal. Commenting on this, in his turn, Professor Leyst said that whatever might have been the case in remote times, before Pavlovsk and Potsdam supplied a check on Kew, recent data even at Kew supported his theory, and he quoted from me the results for 1881-4, 1892-5, and 1905-8 representing sunspot maximum, and the results from 1887 to 1890 and 1899 to 1902 representing sunspot minimum. This combination, as Table 2 shows, supported his theory, though less

was only +0.07 γ, a quantity invisible on the ordinary magnetic curve. As a matter of fact, however, we are in a position to say not merely that the daily rate of change in H is not uniform, but further that it differs even in sign on days of different kinds.

It is usual to divide days magnetically into three classes, the quiet, the moderately disturbed, and the highly disturbed, the last class being relatively small. In 1889 a scheme was formulated whereby five representative quiet days a month were selected by the Astronomer Royal, and the diurnal variation on these days was investigated at Greenwich and Kew, and later also at Falmouth. The scheme

TABLE 2.  
*Secular Change Data from Kew.*

Favourable to Dr. Leyst's Theory		Unfavourable to Dr. Leyst's Theory	
Sunspot Maximum	Sunspot Minimum	Sunspot Maximum	Sunspot Minimum
2 periods 6 years 1892-1908	1 period 6 years 1897-1903	5 periods 15 years 1890-1908	4 periods 12 years 1865-1902
1881-1884 — 6'13 1892-1895 — 6'03 1905-1908 — 5'33	1887-1890 — 5'47 1899-1902 — 4'10	1881-1884 — 6'13 1892-1895 — 6'03 1905-1908 — 5'33	1887-1890 — 5'47 1899-1902 — 4'10 1911-1914 — 9'17
Mean — 6'03	Mean — 4'78	Mean — 6'03	Mean — 6'25

strongly than the shorter period 1892 to 1908. Since Professor Leyst's reply, a sunspot minimum, conspicuous among minima for the absence of sunspots, has passed. Combining it with the two previous minima used by Professor Leyst, we get the final results in Table 2. When the next sunspot maximum has passed, Professor Leyst's turn may come again, but after the association we have seen in 1911-14 of an exceptionally rapid secular change and an exceptionally small number of sunspots, it will take a great deal to put his theory on its legs again.

The intensity of magnetic force changes as well as the direction. Thus at Kew between 1890 and 1900 H (horizontal force) increased from 0.18160 to 0.18428 C.G.S. When dealing with such small changes as ordinarily present themselves in terrestrial magnetism, it is convenient to employ as unit 1 γ, or 0.00001 C.G.S. Thus the mean annual rise of H from 1890 to 1900 was 26 γ. After 1900 the rate of increase of H rapidly fell off, and the element seems to have attained a maximum and begun to diminish. V (vertical force) has been diminishing for some time.

#### NON-CYCLIC CHANGE.

As the secular change alters in amount from year to year, we naturally expect slight variations from month to month, or even day to day. But we should not a priori expect to be able to recognize the secular change taking place in the course of 24 hours, much less variations in the rate of change from day to day. If we take 1890 to 1900, when the annual secular change of H had on the mean the substantial value +26 γ, the change in the average 24 hours

remained in operation until replaced by an international scheme, under which the selection of the five quiet days a month is made at the Netherlands Observatory, De Bilt, the choice being based on returns sent there from some 40 observatories scattered over the globe. After the original scheme had been a few years in operation, I happened to notice that in the average selected quiet day H showed an abnormal increase. Taking a mean from the 1,500 selected quiet days of the 25 years 1890 to 1914, this daily increase at Kew has been 2.9 γ. This may seem a trifle, but if every day behaved like a quiet day H would have doubled itself since 1895. The abnormal rise on quiet days is neutralized by a tendency to abnormal falls on disturbed days. If one of these phenomena is more primary than the other, it is probably the fall on disturbed days.

The other magnetic elements also show abnormal changes on quiet days, especially I (the inclination). The average selected quiet day between 1890 and 1900 gave a fall of 0.25 in I; in fact, the fall on five average quiet days equalled the entire secular change of a whole year.

This non-cyclic change, as it is called, on 'quiet days' seems a universal phenomenon, except perhaps in high latitudes. Whatever its cause—whether a reaction from disturbance, or not—it introduces an unforeseen difficulty into the deduction of the diurnal variation from quiet days. A priori it was natural to suppose that the only difference between quiet and disturbed days was that the latter were affected by irregular variations. On this view,

the regular diurnal variation entered equally into the changes exhibited by quiet and by disturbed days, only in the latter it had superposed on it irregular variations, which might conceal the regular ones. To eliminate these irregular variations, it was necessary to combine results from a large number of days, whereas a few quiet days, it was supposed, would suffice to eliminate the trifling irregularities from which practically no day is wholly free. We now know that quiet days are affected by a special element, the non-cyclic change, which is not periodic in the 24 hours, and to get a periodic variation this element must be eliminated. The method of elimination usually adopted is that which is applied in the case of such a meteorological element as temperature, which at certain seasons, spring and autumn, has a general drift in one direction. Suppose, for instance, the average day of a certain spring month shows a rise of  $0^{\circ}24$ . This is at the rate of  $0^{\circ}01$  an hour. The central hour of the day is taken as the pivot. A correction of  $-0^{\circ}01$  is applied at 13h. (*i.e.* 1 p.m.), of  $-0^{\circ}02$  at 14h., and so on up to  $-0^{\circ}12$  at 24h.; while to the forenoon hours are applied corrections varying from  $+0^{\circ}01$  at 11h. to  $+0^{\circ}12$  at 0h. (*i.e.* the first midnight of the day). But even after applying this non-cyclic correction we do not in general, as a matter of fact, get exactly the same magnetic diurnal variation from the selected quiet days as we get when we utilize all days, quiet and disturbed.

#### DIURNAL VARIATION.

To give a full account of the diurnal variation as it presents itself at different parts of the earth would require a large treatise. Here I shall confine myself to data from two stations, and to certain aspects only of these data. The one station, Kew, is fairly representative of the British Isles, though a station in the north of Scotland would undoubtedly show a considerable departure. The other station is that used in 1911-12 as the base station of the National Antarctic Expedition under the late Captain Robert Falcon Scott, R.N. The reduction of the Antarctic observations has been prosecuted at Kew Observatory for the last two years under my supervision. For permission to make a free use of existing data I am indebted to the Meteorological Committee, the Director of the Meteorological Office, and the Committee of the Captain Scott Antarctic Fund.

The tragic fate of Captain Scott is still no doubt fresh in your memories. It produced a great impression on his countrymen, who saw in it evidence that the characteristics on which the nation prided itself in more warlike times still survived. Of this fact there has been abundant evidence during the last two years, but five years ago our critics certainly entertained doubts. The appreciation of courage, and what used to be regarded as more especially manly virtues, is practically universal, but even a scientific audience may have to be reminded that the prosecution of pure science under the arduous conditions prevailing in the Antarctic calls for no small measure of pluck and endurance. It also calls, if success is to be attained, for other qualities, which though making less appeal to the public imagination are perhaps of equal value for the welfare of a nation, *viz.* scientific knowledge and forethought. If I am able to-night to mention important deductions from the Antarctic observations, it is to the

physical observers, Dr. Simpson, F.R.S., and Mr. C. W. Wright, that recognition is in the first place due. In spite of the great difficulties arising from the low temperature and the extraordinarily disturbed magnetic conditions, they secured an almost unbroken record for a period of nearly 22 months. Their success was due in considerable measure to the remarkably steady temperature they secured for the magnetograph by installing it in an underground, or rather under-ice, chamber, and to the wise choice they made of sensitiveness for the instrument. They profited no doubt by the experience of Mr. L. C. Bernacchi, the physicist of the first Scott Expedition, who carried on a very uphill fight most manfully. But it is not everyone who can deal successfully with difficulties of which only the general character is known in advance.

A preliminary word may be useful as to what is meant by the regular diurnal variation of a magnetic element, and the way in which it is calculated. Taking all or a selection of the days of a month, the curves are measured at every hour. The entries for each hour are summed and the arithmetic mean deduced. In this way we get 24 hourly values for the representative day of the month. It is customary to consider not these absolute hourly values but their departures, plus or minus, from the mean of the whole 24. These departures are known as the diurnal variation or inequality. There are variations in the vertical as well as in the horizontal components of magnetic force, but the changes in the latter are usually the larger and more interesting, and most of my remarks will be confined to them. Magnetographs show the variations of D and H, or of two rectangular components of the horizontal force, separately, but the two sets of results may be combined in what is known as a vector diagram. This shows for each hour of the 24 the direction and intensity of the force required to produce the observed departures from the mean value for the day. It is, of course, the representative day of the month or season, not any individual day, that is dealt with. From the point of view of an inhabitant of the earth, the sun goes completely round in 24 hours, appearing to us in England to travel from east to west through south. We see his progress only when he is above the horizon; when below it he travels from west to east through north. In high latitudes at midsummer there is no night, the sun completing his daily course above the horizon, while at midwinter there is no day, the sun remaining below the horizon.

Fig. 5 contrasts the diurnal variations at Kew and at the station of the National Antarctic Expedition. For brevity, the latter diurnal variation is described as Antarctic, but the variation must of course be different at different parts of the large area to which Antarctic, as a geographical term, applies. Vector diagrams are shown for three seasons of the year, termed for brevity winter, equinox, and summer. Winter means the four midwinter months (November to February at Kew, May to August in the Antarctic), summer the four midsummer months (May to August at Kew, November to February in the Antarctic), and equinox the four remaining months (March, April, September, and October). Equinox strictly means the time of the year when day and night are of equal length, but the extension of the term to include the four months which form a transition from winter to summer and from summer to winter is convenient, and I hope permissible.

In the Antarctic, with the exception of about 10 days at the end of each period, the sun was continuously above the horizon during summer and continuously below it during winter. Thus, so far as direct solar radiation is concerned, the difference between summer and winter was enormously greater in the Antarctic than at Kew.

In Fig. 5 the lines NS and EW represent the astronomical north-south and east-west directions. The arms of the cross formed by these two lines represent  $10\gamma$ , the scale of force being twice as open for Kew as for the

The local time was six minutes ahead of that of  $165^\circ$  E. It is on the local time of course that the phenomena really depend.

The vector is the line from the centre of the cross to the observational point representing the hour in question. In reality we know the length of the vector only at the hours, and strictly all we are entitled to do is to draw the 24 lines representing the vector hourly. It is usual, however, to draw as we have done for Kew a continuous curve through the 24 observation points. This may be regarded

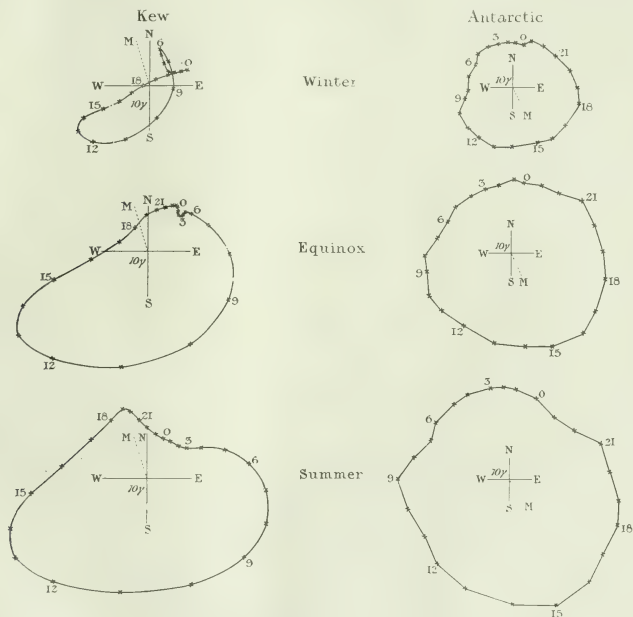


FIG. 5.—Diurnal Variation. Vector Diagrams.

Antarctic. The dotted line from the centre of the cross to M shows the magnetic meridian, or mean direction of the compass needle at the place. At Kew, of course, the N end of the compass needle points west of north. The Antarctic station was situated to the south-east of the south magnetic pole, so that the N end of the compass needle pointed there to the south-east. The hours are counted from 0 (midnight) to 23 (11 p.m.). Greenwich time is used at Kew, but this differs by only one minute from local time. The time adopted in the Antarctic diagrams is that of  $165^\circ$  E. longitude, which is 11 hours fast on Greenwich.

as showing the trace which the free end of the vector would describe if we took measurements at innumerable short intervals throughout the 24 hours. Numerals denoting the hour are attached to every third hour when space permits.

The Kew diagrams are based on the curves of 11 years, the most disturbed days, 3 or 4 per cent of the total number, being omitted. They are thus naturally much smoother than the Antarctic diagrams, which are based on two years only, no days being omitted unless the trace was incomplete. Everything considered, the comparative

smoothness of the Antarctic diagrams is really what is surprising. Take, by way of illustration, the summer diagram for Kew. At 0 h. (midnight) the vector is directed about N.N.E. During the next six hours it gradually points more easterly. At 7 a.m. it points south of east; at 9 a.m. it points S.E. During the next three hours the vector travels round rapidly, passing through south between 10 and 11 a.m., and thus well ahead of the sun. It is longest, *i.e.* the force causing the diurnal inequality is greatest, about 1 p.m.

While the Kew diagrams are described clockwise, the Antarctic diagrams are described anti-clockwise, a natural consequence of the stations being in opposite hemispheres.

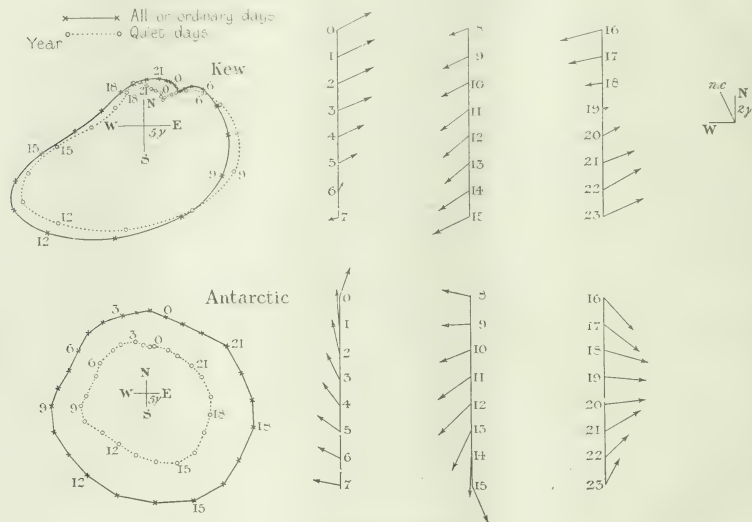


FIG. 6.—Diurnal Variation.

Another and really remarkable feature is that the Antarctic diagrams, though less smooth, are much more nearly circular than the Kew ones. The Kew summer diagram, it is true, shows an approach to symmetry about the magnetic meridian, but it takes the vector nine night hours to sweep through as large an angle as it does between 4 p.m. and 7 p.m. The Kew equinoctial diagram is markedly less symmetrical than the summer one, and a curious little bay shows itself early in the morning. The vector is nearly stationary in direction for some hours. This develops into a retrograde motion from midnight to 6 a.m. in the winter diagram. There is then at least one loop, possibly two, during the night hours.

In the Antarctic, as at Kew, the mean value of the vector

is much smaller in winter than in summer, but the differences in the shape of the diagram at different seasons are so small as to be possibly accidental. There is much less difference between "day" and "night" in the Antarctic than at Kew. This is perhaps not surprising in winter and summer, but it is equally true of equinox.

Fig. 6 represents another and not less surprising difference between Kew and the Antarctic. The vector diagrams all refer to mean results from the whole year. The full-line diagram represents at either station results based on all or all but highly disturbed days, the dotted-line diagram results from quiet days only, the origin, the centre of the cross, being the same for the two. The Antarctic quiet days

(selected by myself) were 10 a month as against 5 at Kew (international quiet days). Thus *a priori* we should have expected less difference between the two Antarctic diagrams than between the two Kew ones. As regards type, there is in fact less difference in the Antarctic, but as regards amplitude the difference at Kew is slight, and not always in favour of the all-day vector, whereas in the Antarctic the excess of the all-day vector is conspicuous at every hour.

Closer examination of Fig. 6 shows another remarkable difference between the two places. If we join the points corresponding to the same hour on the two diagrams for the same station, the line represents in magnitude and direction the force to which the difference between the all-day and quiet-day phenomena may be ascribed. Drawing

these difference vectors, as we may call them for brevity, *in situ* would have confused the Kew diagrams, so I have drawn them separately at the side, using a separate origin for each hour and distinguishing it by a numeral. The arrow helps to show the direction in which the force acts. The line drawn from o, for instance, is parallel to the line joining the points representing midnight on the all

as the vectors themselves, but for Kew the difference vectors are drawn on a scale, shown at the side, more open than that employed in the diagrams in the proportion 5 to 2. Thus the scale used for the Kew difference vectors is five times as open as that used for the Antarctic difference vectors.

Starting at hour 0, we have the Antarctic difference

### Antarctic winter

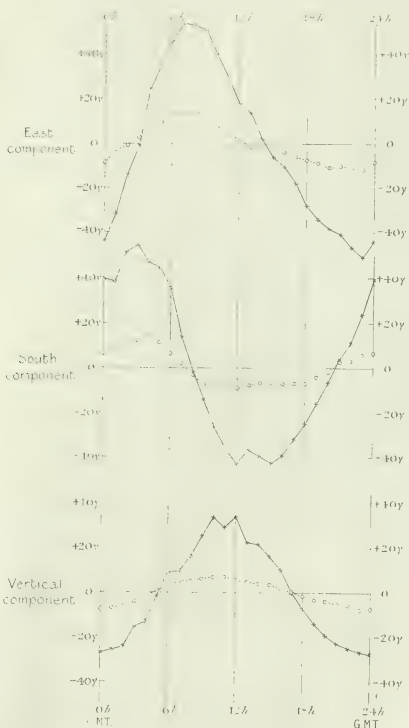
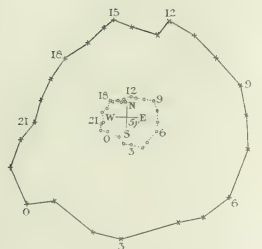


FIG. 7.—Diurnal Variation.

and quiet-day diagrams, and represents in magnitude and direction the midnight value of the force required to turn the quiet-day inequality into the all-day inequality.

The origins for successive hours lie on straight lines oriented north and south, the distance between successive origins in the case of the Antarctic representing  $10\gamma$ . The Antarctic difference vectors are drawn on the same scale

vector inclined slightly to east of north. It then passes to west of north and gradually swings round in the anticlockwise direction, just as happened with the ordinary Antarctic vector. At Kew it is quite otherwise, the difference vector showing a close approach to fixity of azimuth. From midnight to 6 a.m. we have a line pointing in a N.E. direction. Between 6 a.m. and 7 a.m. the vector vanishes

and reappears, having swung round through nearly  $180^\circ$ , so that at 7 a.m. it points to the S.W. It continues to point in this direction until 6 p.m., and between 6 p.m. and 7 p.m. it again vanishes and swings through  $180^\circ$ . Thus at Kew the force represented by the difference vector has a nearly constant azimuth—about  $64^\circ$  east of north—hardly altering except in magnitude.

A curious fact remains to be mentioned. We can represent the non-cyclic effects in the horizontal components as a vector, and the non-cyclic difference vector corresponding to the two sets of days ordinary and quiet at Kew is inclined at  $26^\circ$  to west of north, i.e. is perpendicular to the azimuth we have just found. This non-cyclic difference vector is represented in magnitude and direction by the line marked n.c. in Fig. 6.

The great difference in amplitude between the Antarctic diurnal inequalities from all and from quiet days suggested a comparison between inequalities from highly disturbed days on the one hand and quiet days on the other. To secure a demonstrably impartial selection, I took for each month the five international quiet days selected at De Bilt and the five days which had the largest "character" figures on the international list.<sup>2</sup> Each co-operating station assigns a "character" figure to each day, 0 if quiet, 1 if moderately, and 2 if highly disturbed. If, for example, 32 stations assign a 1 to a particular day, while 8 assign a 2, the international character figure is  $(32 \times 1 + 8 \times 2)/40 = 1.2$ . "Day" in this connection means a period of 24 hours commencing at Greenwich midnight. Thus Greenwich civil time has been used in the curves in Fig. 7, which embody the results obtained for the two sets of days in the Antarctic. When comparing Antarctic results in Figs. 6 and 7, it must be remembered that 11 h. on the former answers to 0 h. on the latter.

Fig. 7 is confined to the four midwinter months, May to August. We have first vector diagrams, with a common origin, for the two sets of days, and secondly three pairs of curves of the more usual type, with time as abscissa and force as ordinate, showing separately the diurnal variations in the south, east, and vertical components. In each case the full-line curve represents the disturbed days, the dotted-line curve the quiet days.

Large as was the difference between the all and quiet-day vectors in Fig. 6, it is quite eclipsed by the difference between the disturbed and quiet-day vectors in Fig. 7. In the latter figure the amplitude of the disturbed-day vector averages about four times that of the quiet-day vector. In fact, the vector for the disturbed winter day averages about the same as the vector of the ordinary summer day.

Fig. 7 shows little if any difference of type between the diurnal variations on quiet and disturbed days, and the ratio borne by the amplitude of the disturbed-day inequality to that of the quiet-day inequality is much the same for the three components of force.

#### SUNSPOTS AND THE REGULAR DIURNAL VARIATION.

The difference in amplitude between quiet and ordinary day diurnal inequalities is, as we have seen, enormously greater in the Antarctic than at Kew. The question natur-

<sup>2</sup> This assumes (see p. 417) that disturbed and quiet conditions present themselves on the same days in the Antarctic as in temperate latitudes.

ally arises whether there is anything at Kew at all corresponding to the Antarctic phenomena. There is, as Fig. 5 shows, a great difference between summer and winter amplitudes at Kew, but there is an equally striking difference in type. The nearest parallel that presents itself at Kew is the difference between the diurnal inequalities in years of many and few sunspots. In Fig. 8 we have drawn from a common origin a vector diagram for the four years 1892 to 1895 combined, representing sunspot maximum, and another for the three years 1890, 1899, and 1900 combined, representing sunspot minimum. The diagrams refer to the year as a whole. The difference in amplitude shown by Fig. 8 is fairly comparable with that exhibited by the Antarctic diagrams in Fig. 6, and the difference in type appearing in Fig. 8 is comparatively trifling. Whether

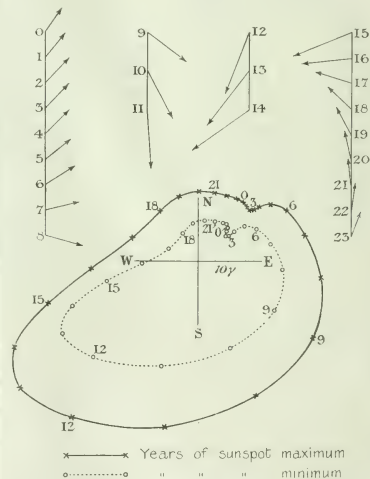


FIG. 8. Diurnal Variation at Kew for whole year.

sunspots are responsible for the difference between the two diagrams in Fig. 8 is not the point that concerns us at the moment. What does concern us is the large difference in the amplitude shown by different years.

Fig. 8 also includes difference vectors, representing the vector which has to be superposed on the vector of the sunspot minimum curve to produce the vector of the sunspot maximum curve. The same scale is employed for the difference vectors as in the vector diagrams themselves. The difference vector in this case swings right round without any tendency to vanish, just as the Antarctic difference vector did in Fig. 6. It will be observed, however, that in Fig. 8 the orientation of the difference vector alters very little from 11 p.m. to 6 a.m. or 7 a.m., and during these hours it shows a pretty close approach to the dominant direction of the Kew difference vector in Fig. 6.

This brings us to the question of the nature of the connection between sunspots and terrestrial magnetism. Scepticism may be felt as to whether the difference between the two diagrams of Fig. 8 was not an accident, of the same kind as the difference between the secular change in years of many and few sunspots to which Professor Leyst called attention. Now, there may be a question as to whether sunspots are the actual source of the magnetic phenomena, or whether they are merely a symptom of other activities in the sun to which the magnetic phenomena are due. Possibly even the solar and terrestrial phenomena have simply a common source, or a common period. But the evidence that on the whole the range of the regular diurnal magnetic inequality and sunspot frequency have waxed and waned together for over 60 years is overwhelming. The relation, be it observed, is not a relation between sunspot and magnetic phenomena on the same day, but between the average of these phenomena during the entire year. The relation was discovered about the same time as the discovery of an apparent connection between sunspots and magnetic storms by General Sabine, to which Lord Kelvin referred in his presidential address to the Royal Society. It was discovered apparently quite independently by Wolf of Zurich, a great authority on sunspots, and von Lamont of Munich, a great authority on terrestrial magnetism. In this country probably the strongest evidence in its favour consists in the comparison made by Mr. W. Ellis, F.R.S., of Wolf's sunspot frequencies and Greenwich magnetic ranges over a very long series of years. The relationship is expressed clearly and concisely by the formula originally advanced by Wolf

$$R = a + bS \dots \dots \dots (1)$$

in which  $R$  denotes the range of the mean diurnal inequality derived from the whole year, and  $S$  the corresponding sunspot frequency, while  $a$  and  $b$  are constants. The formula was originally proposed for declination only, but I have proved it to be equally applicable to the other elements.

Fig. 9 illustrates the application of the formula to  $H$  and  $V$  at Kew from 1890 to 1900. The thick-line curve shows the range as actually observed, the dotted line the range as given by Wolf's formula, the values of  $a$  and  $b$  being calculated in the usual way by least squares, and the values accepted for  $S$  being those published by Professor Wolfer, who succeeded Professor Wolf at Zurich. A priori we should have been inclined to expect  $b/a$  to be at least approximately the same for the different elements at the same station; and, if the effect were a direct one, we should have anticipated that  $b/a$  would prove the same at all stations. Neither of these anticipations seems to be correct. As a matter of fact, at Kew  $b/a$  is larger for  $H$  than for  $D$  or  $V$ ; in other words the diurnal variation shows more dependence on sunspot frequency in the case of  $H$  than in that of the other elements. It is thus all the more noteworthy that it is in the case of  $H$  that the agreement between the calculated and observed ranges as shown in Fig. 9 is closest.

The  $V$  observational data are exposed to greater instrumental uncertainties than the others, and the inferiority of the agreement between observed and calculated  $V$  ranges is presumably partly due to this. There is, however, some

ground to think that the parallelism is really less close in the case of  $V$ . The regular diurnal variation in  $V$  at Kew, as I found some years ago, is much enhanced during disturbed days, while that in  $H$  is not. 1893, though the year of sunspot maximum, was considerably less disturbed than 1892 or 1894, and in 1893 it will be seen the observed  $V$  range fell decidedly short of the calculated.

While it is only a probability that the observed range in 1893 in at least one element fell short of legitimate anticipations, based on Wolf's formula, there cannot be any doubt that in the matter of disturbance 1893 fell notably short of other years of considerably less sunspot development, and this is not an isolated case. Sabine's law is thus on a

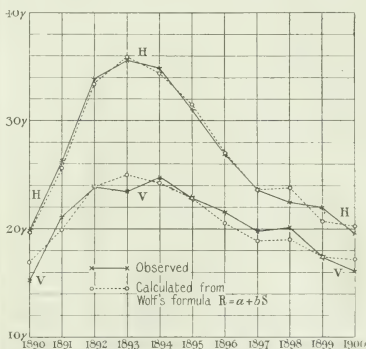


FIG. 9.—Range of the Diurnal Inequality at Kew.

less assured footing than that embodied in Wolf's formula. But the fact remains that years of few sunspots, so far as I am aware, have been conspicuously quiet magnetically. They have not been free from magnetic storms, but disturbance has been much less in evidence than in the average year.

#### SOURCE OF THE DIURNAL VARIATION.

We have already referred to Lord Kelvin's arguments against the theory that the regular diurnal variation is due to the sun's direct action as a magnet. The difference between the phenomena at the different seasons shown by Fig. 5 would certainly be difficult to explain on any such theory. The possibility that the phenomena may be caused by variations in the stresses and strains in magnetic material inside the earth due to the sun's tidal action has been suggested, but seems even less probable. The moon's tidal action is of the same order as the sun's, but the lunar diurnal magnetic variation is relatively insignificant. Again, the tidal action, unlike the magnetic diurnal variation, is comparatively independent of the season of the year. The mere fact of the general parallelism between the range of the diurnal variation and sunspot frequency seems to me to rule out any theory which supposes the principal source internal to the earth. A like conclusion seems almost

inevitable from the observed fact that there is no such lag between seasonal magnetic changes and sun's altitude as obtains in the case of meteorological phenomena. Earth temperature at even a dozen feet shows a lag of months. At the earth's surface temperature shows a lag of weeks, whereas the range of the magnetic elements at Kew and Falmouth, as I have shown elsewhere, has its minimum practically at the December solstice.

On certain hypotheses the question as to whether the source of the diurnal variation is external or internal can be put to mathematical test, assuming of course the existence of adequate observational data. This investigation was first carried out by Professor Schuster, and subsequently by Dr. Fritsche and others. Professor Schuster concluded that the source was mainly at least external. Dr. Fritsche's results rather pointed the other way, but while he employed more numerous data than Professor Schuster they were of a somewhat heterogeneous character. It is, of course, possible that the phenomena in years of sunspot maximum and minimum might lead to somewhat different conclusions, and this point should certainly not be overlooked. I am myself somewhat doubtful whether the problem is yet quite ripe for absolutely conclusive mathematical treatment.

While opinions may differ as to what the phenomena shown by Figs. 6 and 7 really imply, it can hardly be questioned that they have an important bearing on theories which attempt to account for the diurnal variation. A difference in type between simultaneous diurnal inequalities at different places is a natural enough consequence of difference of geographical position. But the influence of disturbance is out of all proportion greater in the Antarctic, and presumably also in the Arctic, than in the temperate latitudes of Europe, and no mathematical formula which contains only geographical co-ordinates and sun's position can adequately meet the case of diurnal inequalities the ratio of whose amplitudes at different places varies from day to day according to the prevalence of disturbance.

The similarity in type between the several Antarctic diagrams in Figs. 6 and 7, and between the Kew diagrams in Fig. 8 suggests that the character of the forces operating is not much affected by disturbance in the Antarctic or by sunspot influence at Kew. If the ultimate cause of the regular diurnal variation is a system of electric currents in the upper atmosphere, the most natural inference is that in years of many sunspots there is a general reduction of electrical resistance in those regions of the atmosphere where the currents flow, and that the same thing occurs, but more especially in high latitudes, on days of magnetic disturbance. It is possible, of course, especially in view of some recent observations by Professor Störmer, presently to be referred to, that it is a case of greater proximity rather than greater intensity of current, arising from reduction in the level where the currents mainly exist.

#### MAGNETIC DISTURBANCE.

Magnetic disturbances remain for consideration. One cannot adequately realize the problem they present without a greater familiarity with their nature than has, I suspect, been possessed by some of those who have theorized on the subject. An erroneous impression seems prevalent that disturbed conditions are exceptional. We

may, of course, so define disturbance that it is a rare event, precisely as we may so define a gale of wind that the term is rarely applicable. But just as absolute quiescence in the atmosphere is rare, so is it rare for any horizontal component of magnetic force to show only the regular diurnal variation. One's view is much influenced by the degree of sensitiveness of the magnetographs. What seems a large disturbance with high sensitiveness appears trifling with low sensitiveness. Some definiteness may, however, be given to the term disturbance by considering its effect on the regular diurnal variation. This is the view that is taken in the international scheme of assigning "character" figures, to which reference has already been made.

"Character" 0 is assigned to those days in which the recognition of the regular diurnal inequality is practically unaffected by disturbance, 1 to those days in which there is interference with the regular diurnal inequality, but not to such an extent as to obscure its general features, and finally 2 to those days in which the diurnal inequality is not satisfactorily recognizable. The mode in which the international "character" figure appropriate to each day is derived from the "character" figures assigned at all the co-operating stations has been already described.

It must be acknowledged that the treatment of "character" figures as if they obeyed the algebraic law  $1 + 1 = 2$  is arbitrary. The energy represented by the disturbances of the average day which gets a 2 is certainly more than twice that represented by the disturbances on the average day which gets a 1, and some days which get a 2 represent the expenditure of 10 times as much energy as others. The standard varies much at different observatories, and, at least at most observatories, it varies with the season of the year, and with the general character of the year. In a quiet season or year, days receive a 2 which in a disturbed season or year would receive a 1. The maintenance of an absolutely uniform standard would mean at the average station few 0's in a disturbed season, and very few 2's in a quiet season. In either case one of the primary objects of the scheme, an adequate discrimination between the days of the same month, would suffer. This latter aspect of the case weighs consciously or unconsciously with most directors of observatories. The consequence is that international "character" figures are not an altogether reliable guide when we want to compare one year or one season with another; but they are—at least for ordinary European stations—a very reliable index of the relative order of the days of the same month as regards disturbance. The observatories contributing to the international scheme represent latitudes from 60° N. to 32° S., but the majority are situated between 53° N. and 20° N., and an undue proportion of them are in Europe. I am not aware of any previous investigation as to how satisfactorily the international figures apply in even the lower latitudes of the southern hemisphere. Whether they would apply at all in the Antarctic was problematical. Disturbance is so enormously greater there than in these latitudes, that it would not have been surprising if no connection had been recognizable.

The matter was first put to the test for entire days. To this end I allotted "character" figures 0, 1, 2 to the Antarctic curves for each period of 24 hours commencing at Greenwich midnight. In assigning these figures, regard

was had solely to the more or less oscillatory character of the trace, and during the process I did not once consult the international lists, so as to be wholly unprejudiced. The standard of disturbance applied was much higher than I have ever applied at Kew, otherwise most days would have got 2's, and few 0's. It will suffice to consider two extreme groups of days, the one composed of the five monthly international quiet days, the other of the five monthly days of largest international "character" figures. These two groups undoubtedly fairly represented, the one quiet, the other disturbed conditions at the average station in temperate latitudes.

It should first be explained that some directors of observatories hardly ever assign 2's, while others assign very few 0's, thus the international figures 2's and 0's are rare. The figures 0's and 1's frequently presented themselves on the international quiet days, while the figure 1's was seldom exceeded on the selected disturbed days, which occasionally included days of "character" less than 1.0. The Antarctic records extended over nearly 22 months, but trace was lacking on a few days. Thus "character" figures could not be assigned to three of the 110 selected disturbed days, and to four of the 110 selected quiet days. The results came out as follows:—

TABLE 3.

*Antarctic Phenomena on International Quiet and Disturbed Days.*

Selected from International "Character" Figures	"Character" Figures assigned to Antarctic Curves			Mean of Antarctic "Character" Figures
	0's	1's	2's	
107 highly disturbed days	0	22	85	1.8
106 quiet days ... ..	57	45	4	0.5

We may thus infer that days of large disturbance in temperate latitudes are always, or almost always, days of large disturbance in the Antarctic; while days that are conspicuously quiet in temperate latitudes are usually quiet, and very rarely much disturbed, in the Antarctic. Three of the four international quiet days, the Antarctic curves of which got 2's, occurred in December 1911, a month to which I had allotted sixteen 2's and only one 0; and all three were on the borderland between "characters" 1 and 2, being essentially quiet, except during a few hours near midnight.

The next step was to compare individual hours. To this end I adopted a method applied by the late Professor Bidlingmaier to the Wilhelmshaven magnetic curves for several years. It is simply an extension of the international scheme, consisting in the allotment of "character" figures 0, 1, 2 to every hour. As the ordinary year contains 8,760 hours, the process is laborious. The operation is simpler when the curves from the three elements appear on the same sheet, as they did in the Eschenhagen magnetograph employed in the Antarctic, than when they appear on separate sheets, as in the Adie magnetographs at Kew and Eskdalemuir.

In dealing with the Antarctic curves I took all three elements into account at the same time. All three had to be quiet to justify a 0, while great disturbance in any one justified a 2. The operation was facilitated by the fact that Dr. Simpson had introduced a device whereby at each hour (G.M.T.) a black line appeared right across the sheet. This rendered it easy to focus attention on the trace belonging to each individual hour. For comparison with the Antarctic, I selected Eskdalemuir, in preference to Kew, because the presence of artificial disturbances at the latter station might well have prejudiced the results. The Eskdalemuir magnetographs record the north (N) and west (W) components—instead of D and H—and the vertical component. Of these V is the least disturbed, and, when it is disturbed, large disturbances practically always present themselves in the horizontal components. Thus I seldom consulted the V traces, but followed the following procedure: I first went through all the N curves of a month, allotting 0, 1, or 2 to each hour. I then did the same quite independently for the W curves. If the same "character" figure had been allotted at any hour to the N and W curves, it was accepted at once as the final choice for that hour. If different figures had been allotted, the N and W curves were compared, and a final choice made. At most hours of the day N is a more disturbed element than W at Eskdalemuir, and on an average about half the hours of a month had to go before the court of appeal. Thus about 1,800 specific acts of judgment were called for in the case of a single month, or about 40,000 for the whole 22 months. In forming a judgment, the gradual movements associated with the regular diurnal variation, which are much more in evidence at some hours than others, were disregarded. No attempt was made to maintain a uniform standard throughout the whole period. The year 1912 was quieter than 1911, and the standards that seemed appropriate to the summer of 1911 and to the winter of 1912 were widely different. The object kept steadily in view was an adequate discrimination between different hours in the same month. The standard applied at Eskdalemuir also varied, but to a less extent. It had no relation to the standard applied in the Antarctic.

Fig. 10 shows the resulting diurnal variation of disturbance at the two places for the three seasons and the year as a whole. As before, winter means May to August in the Antarctic, and November to February at Eskdalemuir. The continuous and broken lines show the diurnal variation in the number of 2's and in the number of 0's respectively. In this case the entry under 1 h., for instance, is for the 60 minutes ending at 1 h. o.m. In the case of the Antarctic the time shown is that of 180° E. long, which was 54 minutes in advance of local time. The Greenwich time used for Eskdalemuir was 13 minutes in advance of local time. The incidence of 2's and 0's is opposite in character; this, though not a priori certain, was anticipated. At Eskdalemuir 2's are above and 0's below their average in the later part of the afternoon, and for an hour or two after midnight. In the Antarctic, in equinox and summer and in the year as a whole, 2's are most numerous about 10 h., or 9 a.m. local time. On the other hand, especially in summer, 0's are very rare in the forenoon. At 8 h. no single 0 was recorded in any summer month. In winter in the Antarctic, the number of 2's is still clearly above the mean in the later part of the forenoon, but the

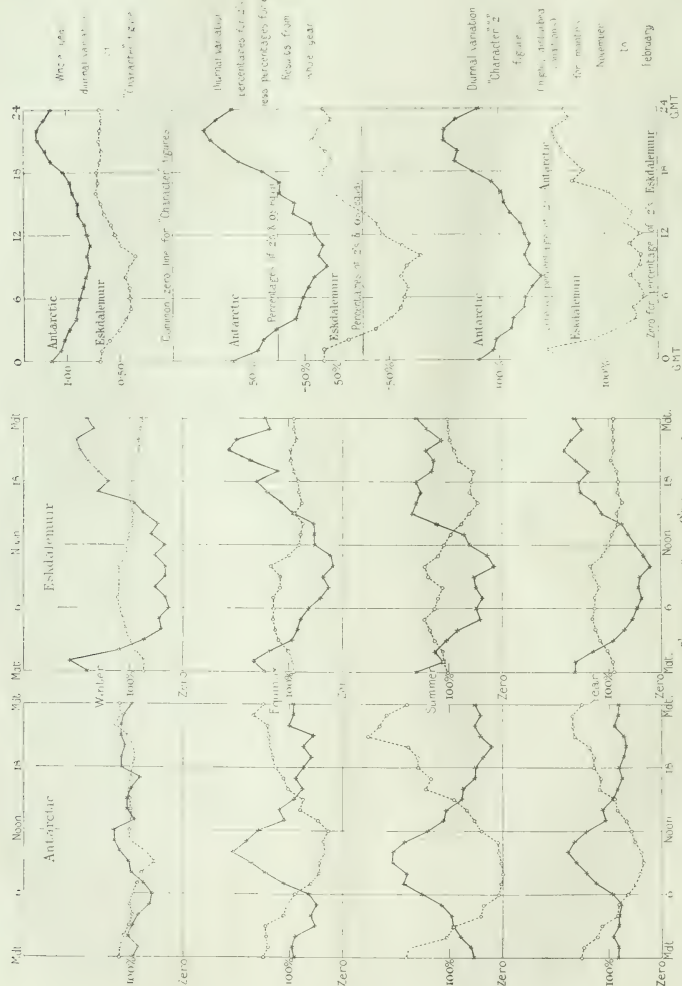


FIG. 10.—"Character" Figures. Diurnal Variation.

Hours of Greenwich Civil Day.  
FIG. 11.

diurnal variation is so much reduced that a considerable period of years would be required to bring it out adequately. All the curves, except those for winter in the Antarctic, show a large diurnal variation of disturbance, but the nature of that variation differs conspicuously at the two stations.

The true inwardness of the results we have found for the diurnal variation of disturbance will be more readily grasped on consulting Fig. 11, where Greenwich civil time is used for both stations. The "character" figures illustrated by the first pair of curves were obtained by adding the 1's and 2's allotted to any particular hour of the 24 as if they were numerals obeying the algebraic law, precisely as is done in obtaining international "character" figures. The second pair of curves, like the first pair, refer to the year as a whole. The procedure in their case was as follows: The number of 2's allotted to any particular hour of the day was expressed as a percentage of the average number (*i.e.* of the total number of 2's allotted to all hours of the day divided by 24). The same was done for the 0's. Suppose, for illustration, the percentages thus obtained for a particular hour were 150 for the 2's and 60 for the 0's, then the difference  $150 - 60$ , or 90, is the quantity plotted. The horizontal line answers to equality in the percentages of 2's and 0's; above it disturbance may be regarded as in the ascendant, while below it quiet conditions prevail.

The lowest pair of curves in Fig. 11 are confined to November to February and show percentages of 2's alone; the horizontal line answers to the average number of 2's.

The general indication of Fig. 11 is that disturbance tends to be in excess simultaneously at the two places, especially at the season when it is largest in the Antarctic. This is, of course, what would happen if there were a general tendency over the whole world towards simultaneity in the *absolute* time of occurrence of the daily maximum of disturbance.

The idea that the average prevalence of disturbance over the globe may be different at different hours G.M.T. may at first sight appear absurd. It must, however, be remembered that the magnetic poles are not on the earth's axis of rotation, and that disturbance may be a function of the local solar time of the magnetic poles, especially of the pole which has the sun above its horizon, and so of G.M.T. Any such conclusion, of course, could be established only by a careful study of data from a number of well distributed stations. In particular, it would be desirable to have simultaneous data from an Arctic and an Antarctic station of similar longitudes, and from two Arctic or two Antarctic stations of widely different longitudes. This may be feasible when the results from the Australasian Antarctic expedition become available. It would also be desirable to have data from years of sunspot maximum, as well as from years of few sunspots like 1911 and 1912.

#### THE 27-DAY PERIOD.

A remarkable feature in magnetic disturbance is the so-called 27-day period. This seems to have been first noticed by J. A. Broun\* in 1858, but the phenomenon for some reason was practically overlooked until rediscovered

by W. Maunder† in 1904 in Greenwich magnetic storms, and about the same time or a little earlier by A. Harvey‡ in Toronto disturbances.

It is perhaps even now not universally accepted, probably from a suspicion that those supporting it are unduly influenced by preconceived ideas as to sunspot influence. Maunder and Harvey both assigned precise periods, the former 27.28 days, the latter 27.246 days, being the identical periods they accepted for the sunspot period. By this they meant the interval between successive direct presentations of a sunspot—in the average solar latitude of sunspots—to the earth, which exceeds the time of the spot's rotation round the sun, owing to the earth's motion in the ecliptic. Magnetic storms, however, generally last for many hours, sometimes for several days, and as no close resemblance exists between the storms associated by Maunder and others with successive presentations of the same sunspot, the interval between the storms can seldom be precisely fixed. All I think we are really entitled to say is that if a certain day is disturbed, days from 25 to 30 days later have more than the usual chance of being disturbed, and this probability is greater for the 27th day than for the 26th or 28th.

Balfour Stewart, in his day one of the leading authorities in terrestrial magnetism, refers to the subject as follows in his important article in the ninth edition of the "Encyclopædia Britannica": "Broun and likewise Hornstein have observed that there is a tendency in large magnetic changes to recur at intervals of about 26 days. At first it was natural to suppose that we have here a magnetical indication of the true time of the sun's synodical rotation, the interval between two disturbances denoting that which elapses between two presentations of the earth of a peculiarly powerful solar meridian." This seems to have been the view taken originally by Broun himself, but Balfour Stewart indicates reasons why, even assuming the cause to be in the sun, the sun's period of rotation should not be exactly indicated, and he points out that the repetitions do not go on indefinitely. Repetitions of storms in about 27 days are, of course, to be expected on any theory, such as that of the distinguished Norwegian physicist Professor Kr. Birkeland, which regards sunspots as the source of an electrical discharge which is the immediate cause of the storm.

If we confine our attention to large magnetic disturbances an obvious difficulty arises. Large disturbances are rare, and if all but large disturbances are disregarded, a very inadequate supply of data remains. If, on the other hand, we count a large number of disturbances as magnetic storms, numerous chance repetitions in 27, or any other specified number of days, must be expected; and in the absence of any precise definition of what constitutes a storm—and none commands general respect—claims as to repetitions in 27 days naturally fail to carry conviction. There are, however, ways of testing the existence of the period less exposed to criticism, and those I have tried point to the real existence of a 27-day period in a certain sense of the term.

The first thing is to get what will be generally accepted as an impartial measure of disturbance, so that days may

\* R.A.S. Notices, vol. 65, pp. 2 and 538, etc.

† Proceedings of the Royal Astronomical Society of Canada, 1902-3, p. 74.

\* Philosophical Magazine, August 1858,

be selected as representative of disturbed conditions, and every day may have a numerical measure attached to its disturbance. International "character" figures naturally suggest themselves for the purpose. These, however, did not exist until 1906, and the period that I was originally interested in was 1890 to 1900. In default of international

ately following these represented conditions one day subsequent to the representative disturbed day, and so on. The "character" figures which I had allotted were entered in 41 successive columns, representing from five days before to 35 days after the representative disturbed day. The successive columns were summed, and the resulting means

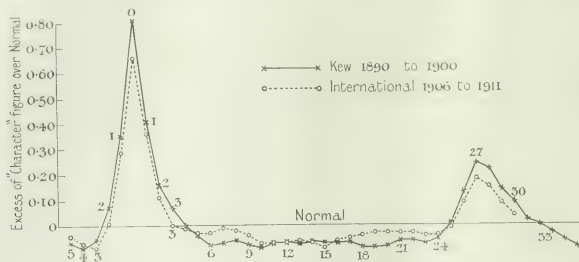


FIG. 12.—27-day Period. "Character" Figures.

figures, I assigned "characters" 0, 1, 2 to every day of the 11 years, using the Kew curves for the purpose. It was, however, impossible by this means to select a definite limited number of days per month to represent disturbance, and even if it had been possible the impartiality of the

taken as a measure of the average disturbance presented from 5 days before to 35 days after the representative day. The total entries of "character" were 27,060 (i.e. 660 × 41), so the labour was considerable. Subsequently a similar investigation was carried out for the years 1906 to 1911,

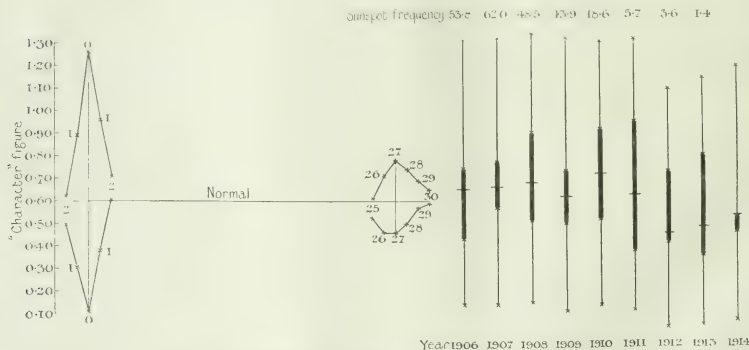


FIG. 13.—27-day Period. International "Character" Figures 1906 to 1914.

choice might have been questioned. Accordingly the criterion adopted was the amplitude of the range of the horizontal force, i.e. the excess of the maximum of the day above the minimum.

The five days of largest range in each month were taken to represent disturbance. The 11 years thus supplied 660 representative disturbed days. The 660 days immedi-

ately following these represented conditions one day subsequent to the representative disturbed day, and so on. The "character" figures which I had allotted were entered in 41 successive columns, representing from five days before to 35 days after the representative disturbed day. The successive columns were summed, and the resulting means

The results of these two investigations are shown in Fig. 12. The ordinates represent the excess above the

mean "character" figure from all days of the period concerned, viz. 0.70 for 1890 to 1900, and 0.66 for 1906 to 1914. The numerals adjacent to points on the curve indicate the interval in days from the representative disturbed day, which is regarded as day 0. The ordinates for days 1 before and after the representative day, though much less than the ordinate for day 0, are still much in excess of the

that it is not peculiar to disturbed conditions, a conclusion which is strongly supported by Tables 4 and 5 and Fig. 13. They show the results of applying the procedure explained above to the international quiet days as well as to the representative, disturbed days of the nine years 1906 to 1914. The representative days in each category were five a month, as before. The normal line in Fig. 13

TABLE 4.  
27-Day Period. "Character" Figures. Disturbed and Associated Days.

Day	2	1	0	1	2	25	26	27	28	29	30	Average Day
1906	0.66	0.93	1.31	1.00	0.63	0.62	0.71	0.74	0.69	0.68	0.63	0.647
1907	0.61	0.96	1.32	0.96	0.73	0.65	0.72	0.77	0.72	0.71	0.75	0.658
1908	0.68	1.01	1.34	1.08	0.81	0.78	0.90	0.90	0.85	0.70	0.67	0.678
1909	0.66	0.91	1.32	0.99	0.74	0.51	0.55	0.73	0.75	0.72	0.69	0.620
1910	0.77	0.98	1.31	1.04	0.90	0.72	0.83	0.92	0.86	0.85	0.80	0.723
1911	0.59	0.90	1.32	1.03	0.78	0.63	0.76	0.95	0.93	0.78	0.67	0.634
1912	0.43	0.71	1.10	0.81	0.51	0.45	0.63	0.73	0.58	0.51	0.42	0.455
1913	0.62	0.83	1.15	0.85	0.63	0.58	0.72	0.80	0.71	0.63	0.59	0.485
1914	0.55	0.77	1.20	0.86	0.69	0.58	0.59	0.52	0.55	0.61	0.67	0.535
Mean	0.62	0.89	1.26	0.96	0.71	0.61	0.71	0.78	0.74	0.69	0.65	0.604

normal. This merely confirms the well-known fact that large disturbances often extend over two or more successive days. The two curves in Fig. 12 agree in showing a prominent hump having its crest at day 27. This may be called the secondary pulse, the primary pulse being that associated with the representative disturbed day and

represents the mean "character" figure, 0.60<sub>4</sub>, of all days of the nine years. Above this normal line we have the primary and secondary pulses associated with the representative disturbed day, whose "character" figure was 1.26, and below it are the primary and secondary pulses associated with the representative quiet day, whose

TABLE 5.  
27-Day Period. "Character" Figures. Quiet and Associated Days.

Day	-2	-1	0	1	2	25	26	27	28	29	30	Wolfer's Sunspot Frequency
1906	0.51	0.33	0.14	0.37	0.53	0.58	0.47	0.43	0.54	0.63	0.73	53.8
1907	0.53	0.32	0.14	0.42	0.71	0.59	0.51	0.57	0.60	0.59	0.56	60.0
1908	0.58	0.37	0.15	0.41	0.70	0.59	0.49	0.51	0.55	0.60	0.67	48.5
1909	0.48	0.32	0.11	0.34	0.58	0.60	0.55	0.50	0.49	0.51	0.58	43.0
1910	0.62	0.37	0.14	0.46	0.76	0.69	0.50	0.52	0.52	0.60	0.75	18.6
1911	0.53	0.36	0.12	0.44	0.68	0.46	0.35	0.38	0.40	0.65	0.65	5.7
1912	0.43	0.26	0.04	0.31	0.58	0.37	0.41	0.42	0.49	0.57	0.49	3.6
1913	0.36	0.23	0.05	0.29	0.45	0.35	0.34	0.36	0.43	0.43	0.48	1.4
1914	0.47	0.25	0.07	0.35	0.51	0.52	0.48	0.47	0.43	0.47	0.42	?
Mean	0.50	0.31	0.11	0.38	0.61	0.53	0.46	0.46	0.50	0.57	0.59	—

adjacent days. If there is any period shorter than the 27-day period, it is obviously comparatively insignificant.

The days recognized by Maunder as magnetic storms averaged only about one a month, and were much more numerous in some years than others. If the 27-day period had been a phenomenon confined to such highly disturbed days, the procedure adopted here could hardly have brought it into evidence, except in disturbed years. It proved, however, to be as much in evidence in the less disturbed as in the more disturbed years. This suggests

"character" figure was 0.11. The secondary pulse associated with the representative quiet day is not quite so deep as that associated with the representative disturbed day, but the same is true and to a like extent of the primary pulses.

Figures that are above the average day value in Table 4 or that are below the average day value in Table 5 are in heavy type.

In 1914 only 55 representative days of either class could be used, because the secondary pulse corresponding to

December days would have fallen in January 1915, a month for which no international "character" figures are yet available.

The graphical representation of the results for the individual years in Fig. 13 is confined to days 0 and 27. The extreme top and bottom of the lines represent the "character" figures on the representative disturbed and quiet days, on the same scale that serves for the nine years combined. The top and bottom of the thickened portions of these lines represent the "character" figures on the days which are 27 days subsequent to the representative disturbed and quiet days respectively. The total length of the vertical line may be regarded as a measure of the primary difference pulse (disturbed less quiet), and the length of the thickened portion as a measure of the corresponding secondary pulse. The short horizontal line shows

better developed than the secondary quiet pulse, and 1913 shows the same phenomenon to a minor extent. In 1906, on the other hand, the secondary quiet pulse is the more prominent. In the years 1907 to 1911 the development of the two secondary pulses is very similar.

I have extended the procedure up to the 84th day subsequent to the representative disturbed and quiet days, and have also gone backwards to the 84th day prior to the representative days, making use of the international "character" figures of the years 1906 to 1911. Besides the primary pulse, whether disturbed or quiet, this disclosed three secondary pulses with crests at about 27, 54, and 81 days after the representative day, and three secondary pulses with crests at about 27, 54, and 81 days before the representative day. These are shown in Fig. 14. Corresponding antecedent and subsequent

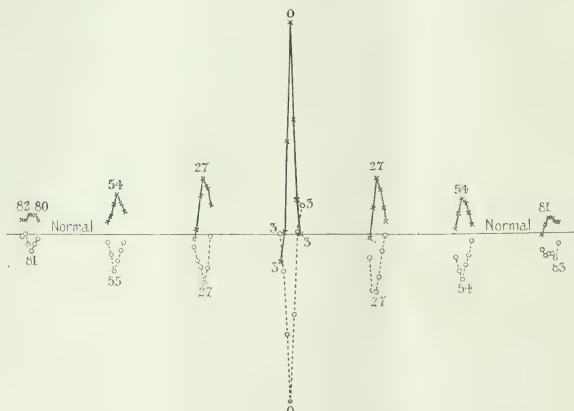


FIG. 14.—27-day Period. International "Character" Figures.

the "character" level of the average day of the year. The lengths of thickened line above and below this level may thus be regarded as representing respectively the amplitudes of the secondary pulses of disturbed and quiet conditions. Above the nine lines are given Wolfer's mean sunspot frequencies for the respective years; his frequency for 1914 is not yet available.

The 27-day period is conspicuously shown in Fig. 13 in every year except 1914, where the secondary pulse associated with the representative disturbed day is abnormal. There is in 1914, as Table 4 shows, a distinct disturbance secondary pulse, but it is more suggestive of a 30- than a 27-day period. The two years in which the 27-day period is most in evidence are 1911 and 1913; both, especially the latter, years of few sunspots; while 1907, the year of sunspot maximum, shows it less than any other year except 1914. In 1912 the secondary disturbed pulse is much

pulses are closely similar. The amplitude of the successive secondary pulses becomes less and less, and the pulses 81 days before and after the primary one are of somewhat irregular outline. The phenomena might have several explanations. All or the majority of disturbances might repeat themselves after 27 days with reduced intensity; or a minority of the disturbances might recur with no reduction of intensity; or there might be any intermediate state of matters. The similarity in amplitude of the antecedent and subsequent secondary pulses suggests the recurrence of a minority only of the disturbances, and with little alteration of amplitude on the average. This is also the conclusion to which a study of individual cases points.

The 27-day period phenomena exhibited by disturbances undoubtedly afford some support to the sunspot origin theory. Some sunspots present themselves for several

solar revolutions, while many are short lived and do not recur. It is thus of interest to compare the recurrence phenomena in sunspots and disturbance. Primary and secondary sunspot pulses are easily studied by utilizing the daily sunspot areas published in the annual Greenwich volumes. The areas I have employed are those known as "projected." As a spot of constant area approaches the solar limb its apparent size diminishes, varying as the area projected on the luminous disk. The five days a month of largest projected area were taken as representative, and the areas for these and for days previous and subsequent were entered in separate columns, exactly as was done in the case of the magnetic "character" figures. Fig. 15 contrasts primary and secondary pulses of the two elements, arrived at quite independently of one another. The ordinate shows the sunspot areas or "character" figures, as the case may be, expressed as percentages of

earth; and this again is quite in harmony with the views expressed by some of those who support the sunspot theory of disturbance.

Fig. 16 shows the results of two attempts to push the inquiry further. The top pair of curves refer to the years 1906 to 1910. The five days of largest international "character" in each month were taken, and Greenwich sunspot areas were put down in successive columns for these, and for a number of previous and subsequent days. Summing and "meaning" the spot areas in the successive columns, one got a sunspot-area pulse associated with days representative of large magnetic disturbance. The figure contrasts the pulse so found with the primary magnetic pulse for the same days. Both sets of results are expressed as percentages of the average or normal value of the corresponding quantity for all days of the five years. The scale of ordinates is, however, five times as

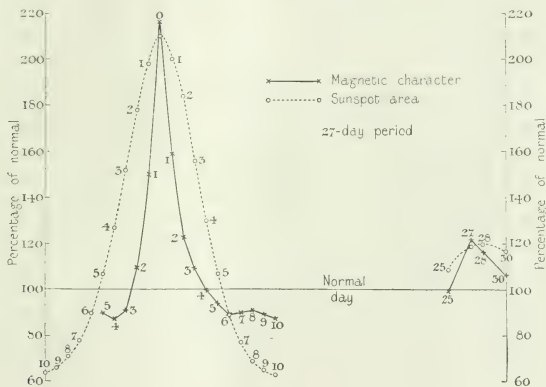


FIG. 15.

those of the average or normal day. The two primary pulses, as a matter of fact, refer to one period, 1890 to 1900, the two secondary pulses to another period, 1906 to 1910. The maximum ordinates of the primary pulses for the latter period were for spot areas 222, and for "character" figures 198, and so were not much different from the corresponding ordinates for the earlier period. I preferred to use the earlier period for the primary pulses, because it was the only period for which the shape was known for a large number of successive days.

As Fig. 15 shows, the 27-day period is very similarly developed in sunspot areas and magnetic "character," so far as amplitude is concerned; but the sunspot pulses, both primary and secondary, are much rounder in shape than the "character" pulses. This, however, might be explained by supposing that sunspot areas are practically effective as sources of magnetic disturbance only when close to the sun's central diameter as viewed from the

open for the secondary (*i.e.* sunspot area) curve as for the primary (magnetic "character") curve. At first sight, the result looks very favourable for the view that the sunspot area is the effective cause of magnetic disturbance. The maximum of sunspot area appears on the same day as that of magnetic "character," and the spot area curve has a regularity and symmetry which can hardly be regarded as accidental. The very rounded shape of the spot-area curve is, however, again a difficulty. The difference between the spot areas on the representative day of large magnetic "character" and two days before is only about 4 per cent of the normal area, while the corresponding difference of magnetic "character" represents 100 per cent of the normal.

The lower pair of curves in Fig. 16 show the results of another investigation, the converse of the last. They refer to the longer period 1890 to 1900. In this case the five selected days a month were those of largest spot area, and

the primary (sunspot) curve was thus the same as that represented in Fig. 15. The material used to form the secondary (magnetic) curve consisted of the Kew H daily ranges. The ordinates represent the results, whether spot areas or H ranges, as percentages of the normal or average day value, the scale of ordinates being again five times as open for the secondary curve as for the primary. The secondary curve shows a decided pulse, with some resemblance to the primary pulse, but the crest of the secondary pulse follows four days after that of the primary. On the day when spot area has its maximum, the magnetic range is very little above the normal. It does not seem easy to reconcile this with the view that the spot area is the direct cause of magnetic disturbance, and that its effect is practically limited to a day or two on either side of its transit across the central solar meridian.

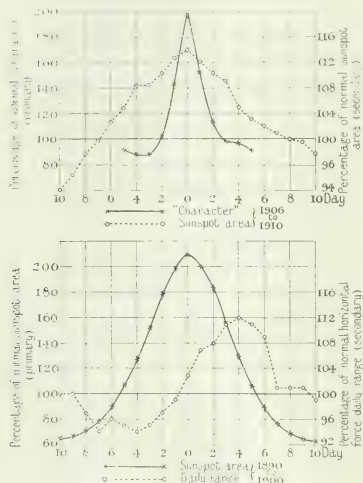


FIG. 16.—Primary and Secondary Pulses.

This second investigation was repeated, employing "character" figures instead of H ranges, but the result was even less favourable to a direct connection of spot areas and disturbance. There was a decided "character" pulse, with crest four days after that of spot area, the crest representing 9 per cent excess of the normal "character"; but on the representative day of large spot area the "character" was actually 2 per cent short of the normal. The crest, moreover, of the secondary pulse arose not from a prevalence of days of large disturbance, but from a paucity of days of "character" *o*. The day showing the greatest prevalence of "character" *2* was 12 days anterior to the representative day of large spot area, a result more in harmony with the contention of

the late Dr. Veeder that sunspots are most effective as magnetic disturbers when near the edge of the solar disk. I do not think, however, that at present this view meets with any influential support.

Another investigation leading to negative results may be mentioned. If sunspots are the direct cause of magnetic storms, and the result follows at once without a lag, then one would expect spots to be less in evidence than usual on magnetically quiet days. To test this, I calculated the mean value of Wolfer's sunspot frequency (provisional values) for the 660 quiet days selected by the Astronomer Royal for the years 1890 to 1900. The resulting mean frequency was 41.28, while the mean from all days of the eleven years was 41.22.

A good deal probably remains to be done to unravel the exact nature of the relationship between sunspots and magnetic phenomena. There can hardly be any doubt that the range of the mean diurnal variation for the whole year varies from year to year in almost exactly the same way as the mean sunspot frequency or the sunspot area. Also the two phenomena exhibit a 27-day period, and to approximately the same extent. In the average year of an 11-year period 1890 to 1900 the daily range of H at Kew showed a decided tendency to be above its mean value during several successive days subsequent to the appearance of exceptionally large sunspot area, the maximum in the range following 4 days after the maximum in the area. The phenomenon, however, did not seem to arise from special disturbance, but rather to be a variant of the phenomenon of large regular diurnal variation in years of many sunspots. As regards disturbance, in some years there seems a clear connection with sunspots, in others little if any. This is what we might expect to happen if the 27-day periods in the two elements in one year tended to be in phase, and in another year did not. But the 27-day period may be prominent in magnetic phenomena in years when there are almost no sunspots. Also the 27-day period is exhibited by magnetic calms as well as by magnetic storms, and no one has suggested that limited solar areas can exercise a calming influence on terrestrial magnetism.

#### RECENT NOTABLE WORK.

Of recent years the theoretical treatment of magnetic disturbances which has received most general recognition is due to two Norwegians, Professors Birkeland and Störmer, both supporters of variants of the theory that the cause of disturbances is the emission of electrons from the sun. Professor Birkeland, who was first in the field, held at least originally—he seems of late years to have somewhat modified his views—that sunspots were the actual sources of the solar discharges, the paths of discharge on reaching the earth's atmosphere becoming visible as auroras. The electrons tend to describe spirals round the earth's lines of magnetic force, and thus become concentrated in areas surrounding the magnetic poles. Besides his theoretical work—some of it involving no mean flights of the scientific imagination—Professor Birkeland has done much brilliant experimental work. Using a large magnetized sphere, representing the earth, in a large vacuum chamber, and employing very powerful electrical discharges, he has produced phenomena resembling various

forms of aurora. Also, largely at his own expense, he secured numerous simultaneous records from magnetographs working at several Arctic stations, and comparing these with corresponding records from different parts of the world he added much to our knowledge of magnetic storms, especially those of the type he has called "polar."

Professor Störmer is responsible in the first place for a number of mathematical calculations—some of a very laborious character—for deducing the paths of the electrons emitted from the sun. It must, however, be allowed that objections, apparently of a serious character, have been urged by Professor Schuster against these and similar calculations, a principal criticism being that the mutual interaction of the electrons has been unjustifiably neglected. Another comparatively recent departure of Professor Störmer's is one whose great value cannot be questioned. He has developed a satisfactory method of photographing aurora, and by taking simultaneous photographs from the two ends of a measured base—in his principal series a base of 27.5 kilometres—he has been able to calculate the height and geographical position of a number of auroras. His observations suggest the possibility that auroras do not descend to so low levels in years of sunspot minimum as in years of sunspot maximum. If this should prove to be the case it would be a very important result. His photographs have also served for the comparison of simultaneous magnetic and auroral phenomena, an obviously promising field of investigation.

Another important event of recent years is Professor E. Hale's discovery of the Zeeman effect in spectra from parts of the solar atmosphere where sunspots exist. This is regarded as implying the existence of a strong magnetic field. The most reasonable, if not the only possible, explanation is the presence of whirls or cyclones of electrons, the direction of the equivalent electrical currents, and so the sign of the equivalent magnetic pole, being ascertainable from the observed Zeeman effect. Professor Hale has found that when pairs of sunspots present themselves, the two members show opposite magnetic polarities, just as if they were the free ends of an electromagnet. These results are of great intrinsic interest, though it is not certain that they have any direct bearing on the theory of terrestrial magnetic storms. Professor Schuster, acting again as an efficient refrigerator, has calculated what the effect would be at the earth's distance from the sun of solenoids having

the dimensions of sunspots and the strength indicated by Professor Hale's measurements of the Zeeman effect. The calculated effects are quite insignificant compared with even third-rate magnetic storms. Professor Hale has also applied the optical method to the solar spectrum all over the sun, to ascertain whether there is a general magnetic field as in the case of the earth. He claims to have established the existence of such a field, but the results he has obtained are rather near the observational limit. He differs from Professor Birkeland as to which is the sun's north magnetic pole, and meantime it may be well to suspend one's judgment.

Another important departure of the present century is the inauguration of a "Department of Terrestrial Magnetism" in the Carnegie Institution of Washington, under the energetic leadership of Dr. L. A. Bajer. It has hitherto chiefly devoted itself to a general magnetic survey, a work the practical utility of which will be universally recognized, especially in a nation like our own whose ships are on every sea.

On the question naturally of most interest to my audience, whether terrestrial magnetism has any direct bearing on the problems of electrical engineering, a few words must suffice. If wireless phenomena are affected, as has been suggested, by the greater or less conductivity of the upper atmosphere, one would expect them to have certain features in common with magnetic phenomena. In particular, the 11-year period and the 27-day period might be expected to disclose themselves. If these periods affect wireless to anything like the same extent as they do terrestrial magnetism, there should be no great difficulty in establishing the fact, if systematic observations were directed to that end. Another possibility is that means may be developed for utilizing some of the power that now goes to magnetic storms. This would naturally be most feasible in high latitudes where aurora and magnetic disturbance are most in evidence.

If any of my audience have come here labouring under the mistaken belief that terrestrial magnetism is a remote and quiescent if not stagnant backwater of the scientific ocean, I hope that what has been said will give them a more correct idea of the situation. If we magneticians have not done by any means all we should have liked to do, it will, I hope, be recognized that we have tried to do the best we can with the limited resources at our command.

## DISCUSSION ON

## THE PREDETERMINATION OF THE PERFORMANCE OF DYNAMO-ELECTRIC MACHINERY.\*

## FURTHER CONTRIBUTIONS TO THE DISCUSSION.

Mr. Lydall

Mr. F. LYDALL (*communicated*): It is, I am afraid, a threadbare criticism to make, but it certainly seems to me that the title of this paper is misleading. Surely it would be more appropriate to alter the wording and call it "The Predetermination of the Performance of Alternating-current Dynamo-electric Machinery." It is not only that the subject matter in the various appendixes relates almost exclusively to alternating-current machines, but in my opinion the calculation form is not particularly suitable for continuous-current generators and motors. On examining the general method and the calculation form put forward, and considering how far they lend themselves to the treatment of continuous-current machines, one is faced at once with the question: What is the precise purpose intended to be served? I find it somewhat difficult to reply to this by studying the paper. There are perhaps two alternative purposes for which a calculation form is intended, possibly more than two. It may be used simply as a convenient means of producing the performance curves of a machine previously designed in all essential particulars. Or it may be used as a form on which are entered the various calculations which have to be made in determining the proportions of the various parts and the windings, etc. Or again, to be more ambitious, it may be intended to serve both purposes. Now the calculation form advocated by the author is quite inadequate for calculating the performance curves of a continuous-current railway motor. Only three points are provided for on the magnetization curve; no space is left for calculating the speed curve or the tractive-effort curve. On the other hand if the form is intended for entering up the design calculations, its primary function should be to show at a glance to the chief designer, who has to be responsible for the design, that the fundamental quantities and considerations have been properly attended to and that safe limits have not been overstepped. Testing the suggested form by applying it to the design of a continuous-current railway motor, I find no space for entering up the maximum peripheral velocities of armature, commutator, and gearing, the maximum voltage between commutator segments at various speeds and with various degrees of field shunting, the additional field ampere-turns required to compensate for distortion due to armature reaction, the number and dimensions of brushes, the calculation of the commutating field, and other matters. Several of these ought certainly to be watched in any continuous-current machine and not only in railway motors. It seems evident, therefore, that the calculation form was not drawn up bearing in mind the needs of a designer of continuous-current machinery. I am also of the opinion that it would be better to use separate forms for working out the designs of different classes of machines, and I cannot see that there is likely to be much gain in using

a common form in order to facilitate the transference of Mr. Lydall an improvement from one class of machine to another. I may perhaps suggest that whatever form is employed, it should be arranged with a single column on each page indicating in words or symbols the quantity to be calculated, with a number of blank columns in which the numerical quantities can be inserted. This enables several attempts at producing a satisfactory design to be made on a single form, which has the great advantage that a record is kept of the unsuccessful attempts as well as of that which is finally adopted. I should like to ask the author what precise meaning is to be attached to the maximum induction in the gap in the case of continuous-current machines. Is this the maximum induction with no load in the armature, or when the field is distorted due to armature reaction? If it is the latter, the value of the voltage constant  $K_v$  is different for each different condition of operation.

With regard to the estimation of iron loss, I fully agree with the author that this is not susceptible to precise calculation. My own experience goes to show that for generators and motors where the core length is small compared with the diameter, the additional iron loss due to eddy currents induced in the castings or end-plates which clamp the laminations is important under all conditions and especially so as saturation increases. With such machines this additional loss may easily swamp the losses in the core plates due to hysteresis and eddy currents. It is chiefly noticeable from the fact that at high saturations the total iron loss is not proportional to the first or second power or even the third or fourth power of the flux density in the teeth and core plates, but follows very roughly the shape of the magnetization curve. In 1905 I worked out the results of a number of tests on the iron loss in machines of various sizes and particulars, and arrived at a formula for the additional loss in the castings or end plates as follows <sup>†</sup>:-

$$\text{Additional loss in watts} = 1.15 d \left( \frac{A T}{s} \right)^2 \times 10^{-8}$$

where  $d$  = diameter of end plate in inches;

$A T$  = ampere-turns per pole for air-gap + teeth;

$f$  = frequency (= r.p.m.  $\times$  number of poles/120);

$s$  = depth of slot in inches.

It is, of course, purely an empirical formula and naturally cannot claim any degree of precision.

The only other point to which I should like to draw attention is the question of cooling by air draught. The formula given is  $h_v = K_v \times v$ , in which  $h_v$  is watts per square centimetre per degree C. difference of temperature between the wall of the duct and the air. The intention of the formula is to provide a means of estimating the

\* Paper by Professor Miles Walker (see pp. 245 and 389).

<sup>†</sup> *Electrical Review*, vol. 57, p. 4, 1905.

temperature of the duct wall if one knows the temperature of the air. But the temperature of the air, at all events where it issues from the duct, depends upon the amount of heat absorbed in its passage along the duct. The method therefore seems to partake of the nature of an argument in a circle. For example, suppose air is blown through a machine at a certain rate, resulting in a certain temperature in the machine and a certain temperature of the issuing air. If the rate of forced draught is doubled or quadrupled, it does not follow that the temperature of the issuing air remains the same as before and that the watts per square centimetre of cooling surface are doubled or quadrupled. In fact, so far as I know, the result is quite uncertain, and I know of no theoretical basis on which it could be predicted. If the author can throw any light on this point, I think his suggestions would be very much appreciated.

Mr. F. CREEDY (*communicated*): The author has written a paper which must be of great interest to all designers. It is certainly an excellent idea to invite designers to contribute to the discussion some of their pet methods of procedure, and will undoubtedly lead to a discussion of the greatest interest. I append below a method of calculating the regulation of alternators which I have used for a number of years and which is extremely simple and accurate, requiring but a few minutes to complete the entire calculation. I must apologize for the length and tediousness of the deduction which could perhaps be considerably shortened with advantage. I cannot help thinking it rather a pity that the author has limited the scope of the paper to methods of calculating the performance of a given machine. It is really the converse problem which the designer has to solve—the customer specifying the rating and approximate characteristics he requires, while the designer has to find the cheapest machine having the required characteristics. I am quite aware of course that this converse problem might well form the subject of a separate paper or half-a-dozen separate papers, and this is no doubt the reason for its exclusion.

*Voltage regulation of alternators.*—In the present contribution an attempt will be made to reduce the modern methods of calculating the regulation of alternators to a very simple graphical form. As a result of the agitation which took place on this subject some years ago we now have several improved methods whereby we may calculate regulation with tolerable accuracy. These, however, owing to the complex angular relations of the quantities involved, usually require somewhat lengthy calculations, or else a rather complicated diagram. In the following diagram (Fig. J) it will be found that these complexities are eliminated, though the method is, with the appropriate constants, mathematically equivalent to all the methods in which the reactions of the current are resolved in (1) reactance voltage and IR drop; (2) cross-magnetizing reaction; (3) demagnetizing reaction; while we also take account of the varying leakage flux at different field excitations. Among these methods may be mentioned those of Hobart and Punga, Guilbert, and Henderson and Nicholson. These authors in their most recent publications only differ as regards the constants they employ. The diagram which we propose to develop is essentially a diagram of effective air-gap magnetomotive force. The

expression "effective" is used, not in the sense of "root mean square," but with reference to the proportion of armature ampere-turns that are effective in producing flux through the poles, which of course do not cover the entire pole-pitch. It is this fact of course which causes the

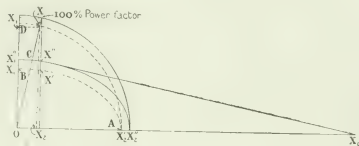


FIG. J.

whole difficulty. We shall resolve, as is usual, the armature ampere-turns into two components: (1) the demagnetizing component  $X_1$ ; (2) the distorting component  $X_2$ .

Let  $X$  = maximum current per phase  $\times$  total turns per pole;

$\psi$  = angle between point of maximum armature current and centre of pole-face, or "internal phase angle";

then  $X_1 = X \cos \psi$ ; and  $X_2 = X \sin \psi$ .

These two components are not equally effective in producing flux, since while  $X_1$  acts on the magnetic circuit of the poles having a comparatively low reluctance,  $X_2$  acts on a circuit at right angles to this and having a much higher reluctance. These facts we express by the introduction of two coefficients which are functions of the ratio of pole-arc to pole-pitch and other factors, and which we shall denote by  $K_1$  and  $K_2$ . Then

Effective demagnetizing ampere-turns  $= X_1' = K_1 X_1$

" distorting ampere-turns  $= X_2' = K_2 X_2$

$$= \frac{K_2}{K_1} K_1 X_2 = K_2 K_1 X_2 \text{ say.}$$

It should be noted that  $\psi = 0$ , which corresponds to zero demagnetizing ampere-turns, is *not* equivalent to unity power factor. In addition to the armature ampere-turns we have acting in the gap the air-gap ampere-turns on the field = total field ampere-turns—ampere-turns required for pole and hub. We are now in a position to construct our diagram. Suppose, for instance, we wish to draw a curve of terminal voltage at constant (full load) armature current and with varying phase angle. Set out along a horizontal axis,  $OX_2$  (Fig. J) the no-load air-gap ampere-turns on the field. To another scale  $OX_1$  may also represent the no-load terminal voltage. The direction of this vector will represent that of the central axis of the pole, while the no-load electromotive force would of course be represented by a vector at right angles to  $OX_2$ . When  $\psi = 0$  (no demagnetization) the armature current will produce a magnetomotive force at right angles to  $OX_2$ . Let  $OD$  represent the effective armature ampere-turns when  $\psi = 0$ , i.e.  $OD = K_1 X$ , where  $K_1$  is the constant mentioned above and  $X$  is the maximum full-load ampere-turns per pole. Let  $OX$  represent the effective armature ampere-turns for any other phase angle of the current. If we suppose the current to remain con-

stant while its phase angle varies,  $OX$  will move on the circle shown dotted. For any value of  $OX$  we shall have, on resolving it parallel and perpendicular to  $Ox_0$ ,

$$OX_1 = \text{distorting ampere-turns} \times K_1$$

$$OX_2 = \text{demagnetizing ampere-turns} \times K_2$$

We have seen that a given number of ampere-turns acts much less effectively in producing distortion than in producing demagnetization. Multiplying  $OX$  by the constant  $K_1$  in order to express this fact, we have  $OX_1 = K_1(OX)$ . Compounding  $OX_1$  with  $OX_2$  we get  $OX'$ , the total effective armature ampere-turns. If we carry out this construction for a few different positions of  $OX$  it will easily be seen (Fig. J) that, as  $OX$  moves on its circle,  $OX'$  moves on an ellipse the ratio of whose semi-axes  $OB/OA = K_0$ , and whose major axis  $OA$  has the same length as  $OD$ . The resultant air-gap flux is due to the resultant of  $OX'$  and  $OX$ . As we noted above, if  $OX$  is any vector representing ampere-turns, the flux corresponding to these will produce an electromotive force differing  $90^\circ$  in phase from these ampere-turns. Now we know that the reactance voltage differs  $90^\circ$  in phase from the current (and is proportional thereto), consequently the ampere-turns required to compensate for the reactance voltage will be in phase with the current  $OX$ . Similarly the ampere-turns required to compensate the voltage-drop due to resistance are in quadrature with the current. Hence, in addition to the ellipse of armature reaction traced out by  $OX'$  we have the drop due to reactance. In order to take account of this we may add a constant quantity  $X'X''$  to each of the axes and trace the ellipse having the new axes, thereby getting another ellipse concentric with the first and with parallel axes. We may also change the scale of  $OX$  so that the length of the major axis of our new ellipse continues to be equal to the radius of the circle. By so doing we shall be able to derive  $OX''$  from  $OX$  by dropping a perpendicular from the new  $OX$  on  $Ox_0$ ;  $X''$  is where this cuts the ellipse. We might also modify the diagram to take account of the  $IR$  drop, but this would lead us to an ellipse whose axes are no longer parallel to those of the original one. As this drop produces a very small effect, except at unity power factor, it appears that this further complication is not justified, but that it is better to subtract the drop direct on unity power factor and neglect it on lower power factors. Hence, finally, the ampere-turns corresponding to the terminal electromotive force will be the resultant of  $OX_0$  and  $OX'$ , i.e.  $X_0X''$ . These ampere-turns are in quadrature with this electromotive force. Hence we get unity power factor when  $X_0X''$  is perpendicular to  $OX$ . Before discussing the value of the constants we must use let us recapitulate the practical method at which we have arrived.

- (1) Set out the field ampere-turns for the air-gap as  $OX_0$ .
- (2) Calculate the armature effective ampere-turns  $K_1X$  and set them out as  $OX_1$  along  $OX_0$ .
- (3) Calculate the reactance voltage, and to the same scale to which  $OX_0$  represents the terminal voltage set off  $X'_1X''$  to represent the reactance voltage, as shown in Fig. J.
- (4) At right angles to  $OX_0$  set off  $OX'_1$  equal to  $K_0 \cdot OX'_1$ .
- (5) Along  $OX'_1$  set off  $X'_1X''$  equal to  $X'_1X'_1$ .
- (6) Draw a quadrant of an ellipse with semi-axes  $OX'_1$  and  $OX'_1X''$ .

(7) Describe a circle of diameter  $OX''$ . This is the locus of the current vector. To find the value of  $X_0X''$  corresponding to a given current, drop a perpendicular on  $OX_0$  from  $X$  and it will cut the ellipse in  $X''$ .

(8) Find by trial a value of  $OX$  such that  $X_0X''$  is perpendicular to  $OX$ . This corresponds to 100 per cent power factor.

The angle between this particular current vector, which we may denote by  $OC$ , and any current vector  $OX$  will be very nearly (though not quite) equal to the external phase angle. It may be conveniently taken to be the same.

(9) To the same scale to which  $OX_0$  represents the no-load terminal voltage  $X_0X''$  will represent the full-load terminal voltage.

A convenient practical method of drawing an ellipse is the following:—Set off the major and minor semi-axes on the edge of a piece of paper (see Fig. K), so that  $OA$  on the paper equals the minor axis  $OA$ , and  $OB$  on the paper the major axis  $OB$ . Then when the point  $A$  lies on the major axis and the point  $B$  on the minor,  $O$  will be a point of the curve, so that by this means

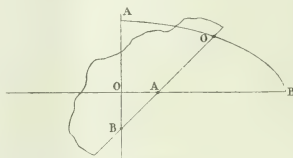


FIG. K.

we can plot it point by point. With regard to the values of the constants to be used in setting out this diagram, great difference of opinion exists, into which I do not intend to go very deeply. Apart from the resistance, these are three in number:—

- (1) The reactance voltage.
- (2) The ratio (effective ampere-turns)/(total ampere-turns),  $K_1$ .
- (3) The ratio of the semi-axes of the ellipse,  $K_0$ .

Both these latter constants are functions chiefly of the ratio of the pole-arc to the pole-pitch, though other variables, such as the number of slots per pole and the degree of chording, should certainly be taken into consideration. The problem, on the solution of which the calculation of these constants depends, is as follows: The armature current produces a wave of magnetic potential around the air-gap periphery, which is shown as  $X$  in Fig. L. This wave of potential is at right angles in space to the wave of current, so that when  $\psi = 0$  (no demagnetization) the wave of current stands exactly above the pole-face, while the wave of magnetic potential is at right angles thereto. In what follows both these waves will be assumed to be harmonic. The field coil produces a certain magnetic potential, which is constant all over the pole-face and is equal to the total magnetomotive force due to the field spool minus the fall of magnetic potential due to the reluctance of the pole and hub. Let  $X_0$  be the magnetic potential (constant all over) at the pole-face; then we may find the magnetic potential at the armature surface by

means of the following formula: Let  $p$  be the permeance per square inch or centimetre at any point P along the air-gap periphery, as mentioned above. Then the flux density at that point  $= X_p p$ . Let the angular pitch of the pole be  $\pi$  radians, or  $180^\circ$ . Let the angular pole-arc be  $\alpha$  radians. Let  $X$  be the maximum magnetic potential due to the armature current, and the magnetic potential at any point  $\theta$  be  $X \cos(\theta - \psi) = X(\cos \theta \cos \psi + \sin \theta \sin \psi)$ ;  $\theta$  is here the angle between a radius drawn to any point P and the left-hand side of the pole-pitch; and  $\psi$  is the

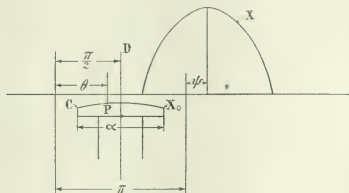


FIG. L.

"internal phase angle" defined above. Let  $X_0$ , a constant quantity, be the magnetic potential at the pole-face due to the field ampere-turns;  $p_0$  the maximum permeance per square inch of the air-gap at the point where it is shortest; and  $p_0 \sin \theta$  the permeance per square inch at the point P. These quantities are all represented in Fig. L. The flux density at any point P along the air-gap periphery will now be

$$X_0 p = X_0 p_0 \sin \theta,$$

which will also of course be the flux density at a corresponding point along the pole-face. The flux density due to the wave of armature magnetic potential  $X \cos(\theta - \psi)$  will be

$$X p \cos(\theta - \psi) = X p_0 \sin \theta \cos(\theta - \psi).$$

The wave  $X \cos(\theta - \psi)$  of course varies in position relative to the pole as  $\psi$  varies, or in other words according to the power factor of the load; but whatever its position it may always be resolved into two components

$$X_1 = X \sin \theta \sin \psi, \text{ the demagnetizing component,} \\ \text{and } X_2 = X \cos \theta \cos \psi \text{ the distorting component.}$$

We assume that  $p = 0$  in the space between the pole-tips.  $X_2$  of course is zero when  $\theta = \pi/2$ , and  $X_1$  is a maximum at this point. Our problem is to calculate the flux due to the resultant of  $X$  and  $X_0$ , and to express it in terms of  $X$  and  $X_0$ . Let us first by way of example calculate the field flux due to  $X_0$ . The quantity  $p$  was defined, not as the total permeance of the magnetic circuit, but as the permeance per square inch. We desire to express the field flux as the product of  $X_0$  into an average permeance  $p'$ .

$$\text{Average permeance } p' = \frac{(2/a) \int_{-\pi/2}^{\pi/2} \sin \theta d\theta}{\int_{-\pi/2}^{\pi/2} d\theta}.$$

Here we integrate between limits represented by the points C and D, the point C corresponding to  $\theta = (\pi - \alpha)/2$ ,

and D corresponding to  $\pi/2$ , and we double the result. We Mr. Creedy then divide by  $a$  to get the average permeance over the whole pole. Carrying out this integration we get

$$\begin{aligned} (2/a) \int_{(\pi - \alpha)/2}^{\pi/2} \sin \theta d\theta &= (2/a) \left[ -\cos \theta \right]_{(\pi - \alpha)/2}^{\pi/2} \\ &= (2/a) [\cos(\pi - \alpha)/2 - \cos(\pi/2)] \\ &= (2/a) \sin(a/2). \end{aligned}$$

$$\therefore \text{flux per pole} = (2/a) p_0 X_0 \sin(a/2).$$

In the above calculation  $X_0$  was constant. We desire to express the flux due to  $X_2$  and  $X_1$  in the same way, viz. as the product of  $X_2$  and  $X_1$  into an average permeance. In order to do this we must merely substitute

$$X_1 = X \cos \theta \cos \psi, \quad X_2 = X \sin \theta \sin \psi$$

for  $X_0$  in the calculation given above. We then get

$$\text{Flux corresponding to } X_2 = X p_0 \sin \psi \int_{(\pi - \alpha)/2}^{\pi/2} \sin^2 \theta d\theta.$$

$\therefore$  Average flux density over whole pole

$$\begin{aligned} &= X p_0 \sin \psi \cdot (2/a) \int_{(\pi - \alpha)/2}^{\pi/2} \sin^2 \theta d\theta \\ &= X p_0 \sin \psi \cdot (1/a) \left[ \theta - \frac{1}{2} \sin 2\theta \right]_{(\pi - \alpha)/2}^{\pi/2} \\ &= \frac{1}{2} X p_0 \sin \psi \left[ 1 + (\sin \alpha)/a \right]. \end{aligned}$$

Similarly, the flux corresponding to

$$X_1 = X p_0 \cos \psi \int_{(\pi - \alpha)/2}^{\pi/2} \sin \theta \cos \theta d\theta.$$

$\therefore$  Average flux density over the whole pole

$$\begin{aligned} &= X p_0 \cos \psi \cdot (2/a) \int_{(\pi - \alpha)/2}^{\pi/2} \sin \theta \cos \theta d\theta \\ &= X p_0 \cos \psi \cdot (1/a) \left[ -\frac{1}{2} \cos 2\theta \right]_{(\pi - \alpha)/2}^{\pi/2} \\ &= (1/a) X p_0 \cos \psi \cdot \frac{1}{2} (1 - \cos \alpha) \\ &= (1/a) X p_0 \cos \psi \sin^2(a/2). \end{aligned}$$

Thus the constants  $K_0$ ,  $K_1$ , and  $K_2$  mentioned above have the following values:—

$$K_2 = (1/2a)(1 - \cos \alpha) = (1/a) \sin^2(a/2) = \text{Distortion constant.}$$

$$K_1 = (1/2a)(\alpha + \sin \alpha) = \text{Demagnetization constant.}$$

$$K_0 = K_2/K_1 = (1 - \cos \alpha)/(\alpha + \sin \alpha) = 2 \sin^2(a/2)/(\alpha + \sin \alpha) \\ = \text{Ratio of semi-axes.}$$

The above calculation takes into account the rounding of the pole-shoe to give a sine wave of flux. Messrs. Henderson and Nicholson have given a similar calculation where this is not taken into account.

The values of  $K_0$  and  $K_1$  arrived at on these two assumptions are plotted as functions of the ratio pole-arc to pole-

Mr. Creed. pitch in Fig. M, curves I and III. It will be seen that they are in very fair agreement, the curves for  $K_0$  only differing considerably for very wide pole-arcs. Curves II are those given by Hobart and Punga, who also consider a constant air-gap, and curve IV corresponds to the simplest possible assumption, viz. that the ratio of the semi-axes of the ellipse is directly proportional to the pole-arc  $\div$  pole-pitch.

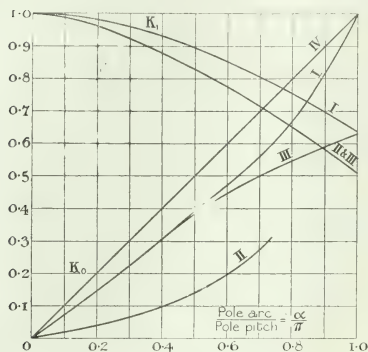


FIG. M.

- I.  $K_1 = \frac{2 \sin \frac{1}{2} \alpha}{\alpha}$ ;  $K_0 = \frac{1 - \cos \frac{1}{2} \alpha}{\sin \frac{1}{2} \alpha}$ . Correct for constant air-gap.  
 II. Hobart and Punga's curves.  
 III.  $K_1 = \frac{1}{2} \left( 1 + \frac{\sin \alpha}{\alpha} \right)$ ;  $K_0 = \frac{1 - \cos \alpha}{1 + \cos \alpha}$ . Correct for rounded pole-shoe.  
 IV.  $K_0 = \alpha/\pi$ .

It will be seen that Hobart and Punga's curve does not check at all well with the others, and in fact it seems questionable to suppose that an interpolar space of only 30 per cent, say, would increase the effective reluctance



FIG. N.

of the circuit of the cross flux by nearly 300 per cent. It is very difficult, moreover, to see the validity of the investigation given in Appendix I of their paper; it therefore seems reasonable to conclude that their value for  $K_0$  is really too low, and that the values in curves I, III, and IV are more nearly correct. However, this is not a point of the first importance, since a wide variation in  $K_0$  only affects the regulation to a comparatively slight extent. The third constant which we require is the reactance voltage due to the leakage flux. This also produces a comparatively slight effect, and its exact calculation is

therefore not very essential. Hobart and Punga give the Mr. C. following rule:—

$$\text{Lines per ampere-conductor per cm. of embedded length} = N_1 = 0.63 (D \times d)/w \text{ (see Fig. N).}$$

$$\text{Lines per ampere-turn per cm. of free length} = N_2.$$

Slots per pole per phase	$N_1$
1	0.8
2	0.7
3	0.6
4	0.5

From which we may deduce

$$\text{Reactance volts} = i(P/P/2)2\pi t(2t \text{ or } l) [N_2 L_1 + 0.63(2bD + d)/w] \times 2.54$$

in inch units.

Where  $P$  = no. of poles  $[P/2]$  is used for consequent-pole windings; ;

$b$  = net core length ;

$t$  = turns per pole per phase.

From which we may deduce

$$\text{Reactance volts} = i P \times 2 \pi f l^2 [N_2 L_1 + 0.63 \times 2b(D + d)/w] \times 2.54$$

for a drum winding. The reactance volts are twice as great in the end connections of a consequent-pole winding. In the above formula

$b$  = net core length ;

$L_1$  = length of both end windings ;

$f$  = frequency ;

$t$  = turns per pole per phase ;

$i$  = current.

If the machine is highly saturated the increased field leakage due to the relatively great field ampere-turns necessary to keep up the voltage at full load will cause a higher saturation than would occur if there were no leakage. In calculating the field ampere-turns at full load this must be also allowed for, though it is negligible if the machine is not highly saturated.

Professor MILES WALKER (*in reply*): I agree with Mr. Lydall that my calculation sheet is not well adapted for the design of railway motors. It does, however, contain spaces for quite a number of the figures which he gives as important. Mr. Lydall's formula for the calculation of the extraneous losses, coming from one who has had such a large experience of practical design, is very acceptable. The determination of the temperature rise on open machines, where the quantity of air flowing through the ducts is unknown, is necessarily an uncertain matter; but if we take the velocity of the air through the duct as being in some way proportional to the speed of the machine, the coefficient being founded upon our experience of the machine in question, then it is possible to arrive at a better idea of the amount of heat dissipated by the walls of the ducts than if we simply allow a constant number of watts per square centimetre, as was the practice of most designers a few years ago. My rule for well-made radial ducts in a stator is to take the velocity of the air in the duct as one-tenth of the peripheral velocity of the

rotor. The velocity of the air in radial ducts in a rotor is usually much more than this, and can sometimes be roughly calculated from the centrifugal head produced by the rotation. Where there are numerous obstructions to the path, it does not in some cases exceed one-fifth of the velocity of the rotor.

Mr. Creed's method of calculating the regulation of alternators has many good points in its favour. The separation of the distorting ampere-turns and the demagnetizing ampere-turns is quite important when dealing

with salient-pole machines. The method, however, is rather lengthy; and when we take into account the fact that the magnetization curve of any generator cannot be predetermined with very great accuracy, on account of the uncertainty, not only in the quality of the material but also in the degree of solidity of built-up laminations, I am not sure that some of the cruder methods at present employed in actual practice are not, from the point of view of practical utility, of almost as great value as the most refined methods.

Professor  
Walker.

## DISCUSSION ON

### "THE DESIGN OF HIGH-PRESSURE DISTRIBUTION SYSTEMS."

NEWCASTLE LOCAL SECTION, 15 JANUARY, 1916.

Mr. C. VERNIER: The author sets out on page 126 the general principles which must receive attention in considering the economical lay-out of high-pressure systems, and shows very clearly that the problem is not one which can be confined to mains alone, but must include the consideration of other matters that are often overlooked, such as the cost of switchgear, attendance, repairs, etc. Too often, as mentioned in the paper, capital expenditure receives chief attention, doubtless because this is an item readily estimated and an immediate liability, the decision frequently resting with financiers, who usually endeavour to reduce such expenditure to its lowest limit. On page 127 the author deals with the considerations which usually decide whether underground or overhead mains should be used. Generally speaking, although with some exceptions, it is our practice to use overhead mains if it is at all possible to find sufficiently open country and to obtain wayleaves. The latter, as mentioned in the paper, have always been a difficult question, more particularly on account of the time taken to obtain them. It should also be mentioned that since the beginning of the war their cost has greatly increased, and is more than ever out of proportion to the value of the land. There is not so much to be said against overhead mains as might appear from the statement that the average number of serious breakdowns on overhead mains is about double that on underground mains. I can remember the time, not so very many years ago, when the number of breakdowns on underground mains was much more than double what it is now; and it can only be a question of time—and I think but a very short time—before overhead lines become so improved, as the result of experience with local and other conditions, that they will compare most favourably with underground mains. The author has been somewhat cautious in the basis he has taken for his estimates of the life of mains, doubtless in order to disarm possible criticism, but I think he will be quite prepared to agree that the life of underground and overhead mains will certainly be more; in my

opinion it will be probably double the figures given in the paper. I consider that Fig. 1 unduly favours underground mains, as wayleave charges have been included on overhead lines but not on underground mains. As the author points out, it is usually possible to obtain shorter routes for overhead lines than for underground mains in open country where roads are usually few and winding. This frequently results in a saving of quite 20 to 30 per cent on route length; but as underground mains, if taken across country, must bear practically the same wayleave charges as overhead lines, it would be fairer to the overhead system if wayleave charges were added to the cost of underground mains, since the alternative is an increase of the interest charge by 20 to 30 per cent. The paper is obviously intended to prove the case of the interconnected system, but to most of us here it does not require any proving. I think the very thorough manner in which the author has gone into the matter should settle once and for all the question of the interconnected system versus radial systems. It is chiefly a question of the cost of protective gear, and because some types of protective gear increase the initial cost of mains, they are often rejected without pursuing the matter to the end. It is quite right to say that the enormous development which has taken place in this district, as indicated in Fig. A (page 230), is due to the invention of the Merz-Price protective gear. It would have been impossible to deal with the system we have to-day with other protective devices which do not depend on a balance principle. To me the most interesting curve in the paper is Fig. 5, wherein the latitude one has in choosing the section of a cable is shown by considering the total annual cost. Thus, the section can be increased by 40 to 50 per cent by increasing the annual cost by only about 2½ per cent. On page 132 another striking point brought out is that in nearly all cases the economical section gives an overload margin of as much as 100 per cent. The tables on page 137 show very clearly the large saving which can be obtained with the interconnected system as against other systems. One difficulty on radial

Mr.  
Vernier.

\*Paper by Mr. J. R. Beard (see pp. 125, 225, 291, and 370).

Mr.  
Vernier.

systems, as the author points out on page 138, is to get the feeders loaded properly. In regard to the 20,000-volt system, it would have been better if the step-up transformers had been brought in, and their capital cost, as well as their losses, included.

Mr.  
Clothier.

Mr. H. W. CLOTHIER: The paper brings home what even the switchgear manufacturer is at times liable to overlook in his absorbing study of detail, that although switchgear and protective devices are responsible for only a small proportion of the initial cost of the scheme, they have relatively a large share, perhaps the largest, in contributing to the successful running of the whole. For instance, the author reminds us that switches which will not clear heavy short-circuits may do immeasurable damage to the reputation of the system for continuity of supply. Nevertheless it must be admitted that on many large installations the switchgear has to pass through a process of evolution, its strength developing to keep pace with the growth of the short-circuit currents occasioned by extensions to the generating plant. It is conceivable that a time may arrive when anything made or known is incapable of resisting the rupturing forces, and then must come a new and stronger form of switchgear, unless relief is obtained by the introduction of reactances or some devices to restrain the short-circuit currents. However, this development work, and the recurring advance in breaking capacity of switches, have been more serious in the past decade than they need be in the future, in that experiences on some very large powers have been instrumental in creating designs to meet very severe conditions existing in this country, for instance on plant of 50,000 to 75,000-kw. working capacity; but it may not be the best economy on a new system, starting with a moderate load, to install in the first place switches capable of dealing with the ultimate capacity—for one reason this may be an unknown quantity. It seems to me that the right solution therefore in such cases is to use apparatus in a form which can be readily moved from one place to another, for example, from the generating station to a near sub-station, or from a near sub-station to a more remote one. In this way the graduation in the strength of the switchgear at the several parts of the system can be corrected from time to time. For this purpose the gear should be as portable as possible, and of a construction independent of concrete or brick-work cells, girder-work, galleries, and such-like permanent parts of the power house or sub-station building.

Mr. Porter.

Mr. G. L. PORTER: I would first emphasize what the author says regarding the increasing use of electricity for domestic purposes, as it is clear that anything like a general use of electricity for cooking and heating with a possible demand of 6 or 7 kw. per house will necessitate a complete redesigning of distribution systems for urban areas. I am afraid that the advantage accruing to an interconnected system from the diversity of sub-station loads is very largely reduced by aggregation of similar consumers in one area. Along a riverside we have chiefly shipyards, and in another district nothing but collieries, and I know of six neighbouring sub-stations, which supply power to by no means identical workshops, having a diversity factor of 1.08. Although I agree with the author that for faults remote from the power station higher distribution voltages will mean higher fault currents, still for the worst faults—those near the power station, which are practically only limited

by the short-circuit current of the machines—the current will be more nearly inversely proportional to the voltage, and in those cases where the higher voltage is obtained from step-up transformers, the impedance of these will limit the maximum fault current. I am glad that the author advocates more interlocking, as I have always been surprised that so little is used on switchgear and the frail human element depended on so largely. Like protective gear, interlocking always suffers from the fact that its cost is always considered in relation to the switchgear only, instead of to the whole cost of the system and the value of reliable supply. The faults due to its absence are generally the most disastrous and cause the most extensive shut-downs. The curves in the paper are very interesting and bring out clearly several points generally overlooked. But to be strictly accurate the use of standard cable sections will give slightly waved curves instead of the smooth ones shown in Fig. 7, the two coinciding only at points corresponding to the standard sections. I would ask the author for a definition of what he means by the term “practically instantaneous.” On the fastest switches that we have tested, the interval of time from the commencement of switch movement to the “break” is one-quarter of the total time from incidence of current in the relay coil to the “break,” which shows that there is still a good deal of scope for the designer to reduce the loss of time in the auxiliary apparatus—relay and trip coil—and so make the whole operation very much more instantaneous than it is at present. The author shows that a cable of the most economical section for its normal load will carry about 100 per cent overload, so that in the radial system with its parallel cables (which have to carry twice normal load when their neighbour is out of commission) everything works very nicely. When, however, we come to an interconnected system we meet difficulties at once. In Fig. 9 (e) there are eight short cables which normally carry only a tiny equalizing current due to diversity of load, and 16 others which normally feed one sub-station. With any radial feeder out of service, some of these interconnectors will have to feed  $1\frac{1}{2}$  and  $2\frac{1}{2}$  sub-stations respectively, giving overloads much greater than 100 per cent in both cases. In Fig. 9 (a) the corresponding overload for a cable near the corner is 500 per cent—in fact none of the cables in the outer square can be laid down on the lines of most economical section. These figures show that we have to put down quite a lot of spare copper in our ring mains. Reverting to Fig. 9 (e), one would expect that a reduction in the number of radials to six would result in a saving in capital cost. I worked out such a comparison using the author's curves where they applied, but adopting standard sections of cable, and I found that the increase in copper necessary in the “ring” swamped the saving in the radials and gave an actual increase of 13 per cent. In Fig. 9 (g), even if all the cables shown are of the same section, the ratio of emergency to normal load in one of the short cables is 9, and of the power station cables the shortest will carry 122 per cent more load than the longest. Thus even in these simple cases, with all the data perfectly known, the principle of the most economical section is of very limited application. How much more so is it in practice where neither the likely demand nor even the possible demand are known, and a system grows and grows until we get a complicated arrangement like Fig. 8, where so much

copper is interconnected that the short-circuit current almost anywhere is enormous and calls for the most expensive switchgear. The radial system is perfectly sectionized and the saving in losses in the interconnected system is obtained at the expense of much difficulty in limiting the effect of faults to one section. I am not advocating the hopelessly expensive radial system, but wish to emphasize that: (1) a system can be far too much interconnected; (2) the principle of "most economical section of copper" cannot be applied to interconnected systems as it can to radial systems, although it is well worth bearing in mind. If this paper results in a more general consideration of distribution losses when the lay-out of feeders is being decided, it will have served a very useful purpose.

Mr. R. W. GREGORY: With reference to the author's remarks upon the lay-out of the distribution system and to the array of networks shown in Fig. 9, I think he might have dealt a little more leniently with the simple radial system illustrated in diagram (b). The simple radial system has many points in its favour, not the least being its simplicity, and in the case illustrated I think it is possible to simplify it further by omitting the expensive high-tension switchgear at the sub-station ends of the feeders and connecting each feeder either direct to or at least through non-automatic oil-break isolating switches without busbars to the transformers. This arrangement would do away with the need of the objectionable reverse-power relays, would make a simple operating job, and would reduce the annual cost figure given in the second line of Table 1 by some £500. This reduction, however, does not affect the author's deductions to any extent. The obvious objection to the radial system is its inflexibility. It is always difficult to maintain continuity of policy when to do so means unnecessary expenditure. The addition of new sub-stations near the outside fringe of the network would very soon be the cause of its conversion to a series radial system like diagram (j), and any further sub-stations would, from reasons of economy, in all probability be fed by interconnection. In fact it is difficult to see how any growing system, no matter what its original type, can fail ultimately to become an interconnected system. As a further alternative to the systems put forward in the paper, I suggest that a combination of the interconnected and simple radial systems would make a very satisfactory scheme and in dense areas would show some economy. By this combination I mean a series of interconnected switch-houses from which high-pressure mains would radiate to transformer-houses which would contain nothing but transformers and low-tension switchgear, one radial cable per transformer. This arrangement would probably show an economy in cable, in spite of the fact that the radial networks would have comparatively low load factors, as in practice there would be a great saving in the route lengths of the heavier copper interconnecting cables owing to their not having to be looped into consumers' sub-stations, often some little distance from the direct route of these interconnectors. Each of the switch-houses on this scheme would be large enough to justify a competent attendant, who would be in charge of all the high-tension switching on the system radiating from his switch-house. This arrangement would tend to simplify many of the small operation difficulties which occur on

a network containing static sub-stations. With regard to Mr. Gregory the author's remarks on switchgear, I think we all agree with him that a completely interlocked mistake-proof switchgear, which eliminates a large number of the chances of failure of supply, is necessary on any modern system in which maintenance of supply is vital. The present-day tendency in the design and lay-out of electric power plant as a whole is to develop along mistake-proof lines, much as they have done and are still doing on the railways, and to eliminate the chances of human error wherever possible. Where in the past we have been satisfied with instruments which only indicate that such and such an operation is wrong we now require means which prevent this operation. The author hints that there is still much to be done in the design of oil circuit-breakers before they can be considered to have a factor of safety equal to the rest of the plant on a large power system, and I cannot help thinking that oil switches will increase in size considerably before they will get smaller again. The development of oil-switch design does not appear to have kept pace with the development of the plant which oil switches have to control. This is particularly noticeable in America where (if published records are to be believed) they are controlling turbo-alternators of over 30,000-kw. normal capacity with switches which are stated to be incapable of opening circuits of more than 40,000 kw. With this state of affairs one cannot wonder at the booming of reactances on the other side of the Atlantic. In this country, however, a study of some of the more modern designs of oil switches shows that the subject of oil-switch design is receiving active attention, and I believe that our switch designers have every faith in the future of the oil switch. Once the contacts of an oil switch start to move apart one cannot expect more of the switch than that it should break the circuit at the first zero that occurs in the current wave after the contacts have parted. The argument for the present practice of increasing the speed of opening of the switch is that the distance travelled before the first zero is reached, or between zero points, is proportional to the speed of opening, and the chance of the arc reforming after the current has once reached the zero value is perhaps inversely proportional to the distance between the fixed and moving contacts at that moment. From oscillograph records that have been taken from time to time on high-tension switches opening heavy short-circuit currents, it appears to be not unusual for the arc to be maintained until the third zero after the parting of the contacts. Some published oscillograms taken at Niagara a year or two ago show this phenomenon as well as some submitted by Mr. Partridge when discussing the recent paper on reactances by Messrs. Faye-Hansen and Peck.<sup>\*</sup> It seems right therefore to assume that if a reasonable factor of safety is required in a switch, the contacts should continue to move apart at full speed during a time at least equal to that of 5 half-periods in the current curve. Of course having increased both the speed and length of break beyond those which have been usual, we might be doing more than is really necessary; but we do not know, and with the present state of switch design it is probably as well to go to extremes in order to obtain safety. The author draws attention to the importance of the oil-switch

<sup>\*</sup> *Journal I.E.E.*, vol. 52, p. 523, 1914.

Mr. Gregory.

tank. It appears that the majority of failures of oil switches have been not that the switches failed to open circuit, but that they suffered mechanical damage, the tanks were bulged or blown off, the top castings were cracked, or the oil was blown out. Therefore the design of the oil tank is a problem which deserves particular attention. In the early days of oil switches a switch tank was merely an oil container; now it has to be an explosion container. The pressures that might occur inside oil-switch tanks under the worst conditions have not been recorded, and at present the only way to deal with the design of switch tanks is to make them stronger than those which have never yet failed under the worst conditions. A tank which I would suggest is perhaps good enough for use on British power systems is one of steel in which an internal pressure of 500 lb. per sq. in. does not stress the metal more than 12,000 lb. per sq. in. A cast-steel tank 2 ft. in diameter with walls  $\frac{1}{2}$  in. thick will conform to this specification, and we can double the thickness of the walls without materially increasing the cost of the switch. The adoption of tanks to withstand high internal pressures means the abandonment of the rectangular sheet-steel tanks, and with them the single 3-phase switch, on gear which has to control large powers. A single circular tank per phase makes the stoutest job possible. I have mentioned before that I believe oil switches will increase in size considerably before they will get smaller again. By this I mean that until we have a switch so amply designed that it is possible to risk a large power plant against its behaviour, we shall not be able to carry out those tests which are necessary before refinements in design can be considered.

Mr. Carter

Mr. T. CARTER: In regard to vents in switches, I should like to know if these should always be open, or if they should be in the form of a relief valve, so that when an explosion takes place the valve opens and allows the gases to escape. At the top of page 129 the author implies that switchgear should not be proportioned to the capacity of the apparatus it controls. I should like to know if there is any rule which indicates how much greater the switchgear capacity should be than that of the apparatus. Referring to the necessity for freedom from breakdowns, I should like to know if "Pertinax" and similar substances have been found to be permanently useful. I have heard it suggested that in a few years these materials disintegrate and become valueless, but I have not been able to get any information based on extended experience. In regard to Fig. 9 (e) on page 136, a previous speaker pointed out that six feeders would cause the system to cost more than it does with eight. If this be so, I suppose the logical conclusion is to have an infinite number of cables, which might be imagined in the form of a solid copper pavement covering the whole area of distribution.

Mr. Gillott.

Mr. W. A. GILLOTT (communicated): In a paper covering such a wide scope as this it is impossible to bring out all the details one would like, and it is therefore to be expected that the author could only make a passing reference to the subject of networks supplying domestic premises. He mentioned that these networks will no doubt require modification in order to suit the expected developments. I am of the opinion that the modifications necessary during the next few years will be very much larger than many engineers imagine. Since the introduction of cheap

units for domestic purposes, heating and cooking has undoubtedly made large strides, and there is every prospect of the heating and cooking business developing to an enormous magnitude. It is therefore necessary for the engineers who decide the mains systems of large undertakings to look well ahead in this respect. I have recently obtained some figures in regard to the probable maximum demand of a large number of houses where electric heating and cooking are installed, and the results are surprising by their magnitude. I think it will be the usual thing, before many years are passed, to find the majority of houses each using an electric cooker and at least one radiator, making a total capacity of approximately 10 kw. per house. From the demand indicators that have been fixed, I find that the maximum demand is approximately 50 per cent of the installed kilowatts. Therefore, if we take a road of 60 houses, and assume only  $33\frac{1}{3}$  per cent of these houses have a cooker and a radiator installed, the probable maximum demand for one road is 100 kw. It is therefore quite evident that considerable alterations will have to be made to the distribution networks in towns in order to accommodate loads of this nature. Some engineers may consider these figures to be rather high, but I am of the opinion that it is merely a matter of a few years before they will be obtained, especially when one considers the number of gas cookers installed in a large town. In Newcastle the number of gas cookers is, I believe, 14,000. My opinion is, therefore, that we shall ultimately see networks for supplying domestic loads laid out with high-tension feeders to step-down sub-stations at very frequent intervals, in order to accommodate the domestic demand. This will also apply to the business centres of the town, as the larger establishments install electrical cooking apparatus for the meals of the staff.

Mr. F. H. WILLIAMS (communicated): It is very seldom that we get a highly technical and theoretical paper such as this where the author is in the happy position of being able to point to a successful application of his theoretical deductions on a large commercial scale. This is a point in the paper which, I think, cannot be too strongly emphasized. From the point of view of simplicity, the radial system, I think the author will agree, seems ideal, but the engineer who is planning a large network must consider first of all the future, and it is then that the flexibility of the interconnected system, for which I consider the author has made an overwhelming case, scores over the rigidity of the radial system. Such an engineer, considering the merits of the radial system versus an interconnected system, is very much in the position of an engineer considering the problem of trams versus omnibuses in an undeveloped district. If he decides in favour of the former and has accurately forecasted the future development, well and good. If, however, he has not done so a lot of capital will have been sunk unproductively, which would not have been the case had he adopted the more flexible alternative. Troubles in operation are, of course, not confined to any particular type of system, but unless the system has been laid down on a thoroughly sound basis they are liable to increase much more rapidly as the size of the system increases; and I would remind those who, coming in contact with the troubles inevitable to the operation of such a large system as we have in this district, are inclined to yearn for the "flesh pots

of Egypt," that "better a devil you know than a devil you don't."

Mr. W. T. TALLENT-BATEMAN\*: I should like to draw attention to a slight contradiction on page 128, where the author deals with the matter of the relief of pressure in an oil-switch tank. He there attributes the fact of the oil formation failing initially to rise to the surface of the oil, to the inertia of the liquid preventing the tendency to very sudden motion when short-circuit conditions prevail. He further states that very heavy pressures are transmitted hydraulically to the tank walls. In the right-hand column on the same page, moreover, he refers to a type of switch in which the repulsive forces of the arc are used to expel the arc in a sideways direction. In this connection, as in the former one, it is quite evident that the fluid inertia would impede the motion to the same extent, if not more so, on account of the tank sides being perfectly rigid, whereas in the vertical direction there is rather more possibility for play. However, as is well known, there is a strong magnetic blow-out effect produced in the case of parallel arcs in a conductor loop of small diameter; and it seems to me that, apart from the consideration of the smaller current, this feature will, if anything, have greater effectiveness in disrupting smaller powers where the gas formation would not take place with an explosive rapidity. Indeed I am perfectly satisfied, as a result of many tests, that a strong magnetic blow-out serves the very useful purpose of giving a directional feature to the arc, thus keeping it on the outside of the spark tips away from the main contacts and operating rods; further, the repellent action is useful in another direction as it assists in throwing the moving contacts away from the fixed ones. In order to take full advantage of the directional feature and any blow-out effect, it is necessary to provide separate steel oil tanks or magnetic shields for each phase, to prevent mutual attraction or repulsion being exerted between arcs of different phases. I should be glad to hear what the author has found with his experience in this direction. With regard to the question of fixing a vent pipe at the top of the oil-switch tank, I think that the chief function such a pipe performs is not so much to relieve the pressure, although it serves that purpose to a certain extent as a secondary object, but to conduct away the highly carbonized products of the arc, and to carry them entirely outside the oil-switch chamber or cubicle, thus preventing any deposit of carbon or oil on the porcelains. In this respect, too, it should be noted that the smoke produced is much more highly conducting than atmospheric air, and if allowed to remain between the contacts at full potential a short-circuit between phases outside the tanks is almost certain to result. From my experience of oil-switch failures, I have found that this is very often the cause; the circuit has been satisfactorily opened inside the oil tank, but a short-circuit has followed outside the switch. This points to the necessity for the complete covering in of the tanks and the provision of an external vent. I notice the author recommends that interlocks should be employed in connection with high-tension switchgear, and I take it he intends this to refer more particularly to sub-stations where the class of attendance is not so high as in the case of larger stations. It seems to me that, to be satisfactory, a

system of interlocks must be absolutely perfect with no possibility of failure, otherwise it not only defeats its purpose (the prevention of faulty operation) but will almost certainly cause injury or death the first time it fails, the attendant, whose intelligence could have been relied upon, having been led to trust implicitly in the security provided. It is questionable whether interlocks can be made so complete as to meet all eventualities; if they can, the cost must prove excessive, particularly in a large generating station. The interlocking system, if adopted, ought to have the self-setting feature of the semaphore signal, which automatically flies to danger if anything goes wrong with the wire, i.e. it should completely lock itself to prevent unwitting danger if anything should go wrong. This is practically impossible and would prove very annoying if it acted. The interlocks necessarily involve a coupling of the separate poles of the isolating switches, thereby necessitating the use of a greater number of insulators, to the extent of 50 per cent. Again, in a generating station where special operations need to be carried out under emergency conditions, or during station tests, e.g. the unusual operation of isolating switches, the use of jumper cables, etc., the interlocks would prove an annoyance and would need to be rendered inoperative for the duration of the abnormal conditions. Unless they are very carefully refitted again, it is quite likely they may be rendered permanently inoperative, and consequently a source of continual danger. In small sub-stations where the attendance may not be so skilled, interlocks may be advisable, and here the problem is a much easier one to solve owing to the switchgear being smaller and less complicated in every way. With regard to the suggestion that oil switches should be provided for potential transformers when connected right on to the busbars, they are, although expensive, a wise precaution on a large system if the expenditure can be incurred. In many cases potential transformers can be left out altogether or connected elsewhere than to the busbars.

Mr. J. R. BEARD (*in reply*): As Mr. Vernier has been responsible for the erection of several hundred miles of overhead lines, his figure of 20 to 30 per cent for the average saving in route length which they effect, as compared with cables laid along roads, is most valuable. I had hesitated about stating any definite figure, and accordingly Figs. 1 and 7 show comparative figures on the basis of equal lengths, although I pointed out that the route length is usually somewhat reduced by the use of overhead lines. Another remark of Mr. Vernier's to which I should like to call attention is his confirmation that for a distribution system of any size some form of balanced protective gear becomes essential. In my reply to the Scottish discussion\* I have already pointed out that while it does not seem possible for overhead lines ever to be as free from trouble as cable laid under good conditions, this is not to be taken as a condemnation of overhead lines. There is no doubt that, whatever the relative figures, the improvements in overhead lines are reducing the risk of interruption to an extent which quite justifies advantage being taken of their reduced cost. The two questions of the rate of depreciation I have allowed for mains, and the inclusion of step-up transformers, have been dealt with in my reply to the discussion before the Institution.†

\* These remarks were made at the Manchester meeting on 14 December, 1915 (see p. 233).

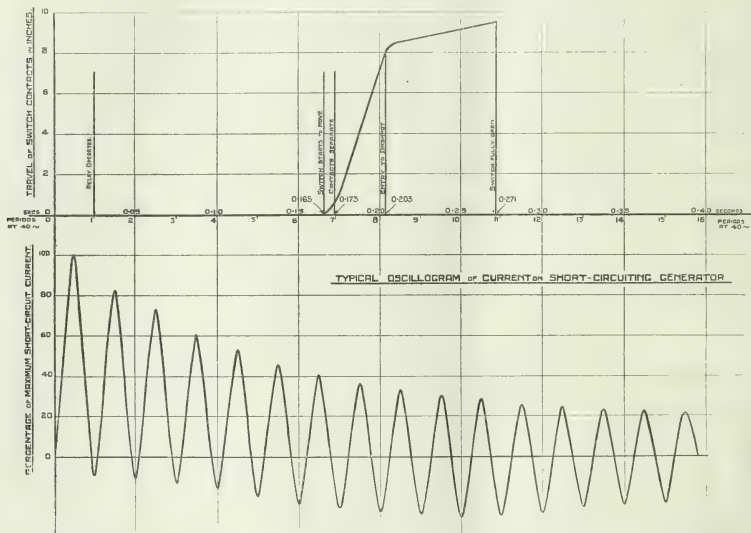
\* Page 381.

† Page 251.

Mr. Beard.

Mr. Clither's ideal of easily removable switchgear, which as it becomes too weak to deal with a growing system can be removed to more outlying parts of the system and be replaced by heavier gear, would not, I think, work out well in practice. Of course it can be done, and as a matter of fact it has been done to some extent on the North-East Coast system, but there are many difficulties in the way of drastic interference with existing switchgear, and the tendency would be to postpone the change until some serious trouble made it imperative.

claims and the question is not at all vital to the case for the Mr. Porter's interconnected system, as it has been omitted in all the comparisons given in the paper. Mr. Porter's qualification of my statement that higher distribution voltages mean higher fault currents, will be useful in removing any misunderstanding. I was only thinking at the time of the sub-station switchgear in general, and I quite agree that for power-station switchgear high voltage is desirable. I am glad that both Mr. Porter and Mr. Gregory support me in advocating more complete interlocking. As their



Maximum Instantaneous Short-circuit Current = Full-load R.M.S. Current  $\times 34$ . Sustained R.M.S. Short-circuit Current = Full-load R.M.S. Current  $\times 3$ .

FIG. D.—Time-position Diagram of Automatic Operation of High-tension Oil Switch, with corresponding Values of Short-circuit Current.

Also the cost of the change would be heavy, as it would have to be carried out at awkward times, and I think by the time the costs were worked out it would prove to have been more economical to have installed the heavier gear at the outset. At the same time the portability of ironclad switchgear is certainly an asset.

The instance of low diversity factor, which Mr. Porter quotes, is a rather exceptional case, and particularly on trunk mains feeding into a group of perhaps 20 sub-stations the diversity is usually considerable. I agree that too much should not be claimed for the saving which diversity effects on an interconnected system, but the figures I give on page 138 do not make any extravagant

opinion is based on experience with a great many types of switchgear, their remarks should carry weight with those engineers who have rather questioned the desirability of interlocks.

As Mr. Porter points out, standard cable sections would result in slightly waved curves in Figs. 6 and 7, but reference to Fig. 5 will show that such waves would be negligible. My definition of the term "practically instantaneous," as applied to the tripping of an oil switch, is: as close an approach to instantaneous action as the mechanism will permit, i.e. with no attempt artificially to delay the action. A diagram of switch movements for a modern switch of the type referred to by Mr. Porter is

shown in Fig. D, and to indicate clearly the relation between the switch movement and the current to be interrupted I have also shown below it a typical oscillogram of the short-circuit current of an alternator. It will be seen that the total time occupied from the instant the protective relay is energized to the completion of the opening of the switch is about 0.2 second. I think this can be justifiably described as "practically instantaneous," although increased speeds will no doubt be obtained in the future by improved mechanism. In all the typical lay-outs shown in Fig. 9, sufficient copper has been allowed for in all cables, including the interconnectors, to deal with the overloads caused by any one of the cables being out of commission. Of course this results in larger copper sections in some of the interconnectors than would otherwise be necessary, but reference to Fig. 5 will show that within reason this does not increase the total annual costs appreciably. In the case of Fig. 9 (e), which Mr. Porter refers to more particularly, I agree that, if the number of radial feeders is reduced, a point is reached at which the additional copper in the interconnectors more than counterbalances the saving in the radial feeders, but on working out the actual figures I find my results do not agree with Mr. Porter's. I make the total annual costs with different numbers of radial feeders to be as follows:—

12 radial feeders	£9,015
8 " "	£8,179
6 " "	£7,793
4 " "	£7,533

It will be seen that the critical point is being approached, but this will seldom occur in practice, as four radial feeders correspond to five sub-stations in series on one interconnecting cable, a number which is seldom reached. Usually more than three or four would be considered undesirable, and in the arrangements shown in Fig. 9 no more than three have been allowed. Fig. 9 (g) is also referred to, and of course if the same size of cable were used throughout, the distribution of current in the cables would be very uneven. In such cases, where the cables vary very much in length, it is important to run the cables as nearly as possible at their economical loading, so as to keep the voltage drop per mile the same on all of them.

Mr. Porter sums up his remarks in two sentences. The first is that a system can be too much interconnected, and with this I am in limited agreement, but the North-East Coast system is the only one in this country which shows any signs of reaching such a point at present. The second one is that the principle of the most economical section of copper can be more readily applied to radial systems than to interconnected systems, and with this I cannot agree at all. Perhaps for the theoretical systems shown in Fig. 9 it may be true, as the sub-station loads are assumed to be definitely fixed; but for all practical systems it will be found that the difficulty of forecasting loads, and generally what other speakers have referred to as the inflexibility of the radial system, result in the feeders on such a system being most uneconomically loaded. This is a point to which I referred more specifically in my reply to Mr. Lang.\*

Mr. Gregory's suggested simplification of the simple Mr. Beard radial system by the omission of high-tension switchgear at the sub-stations would be quite practicable on small systems, and particularly for the small local systems fed from central switch-houses which he suggests later. For very dense areas what he calls the combined interconnected radial system should be very useful, and I referred to such an arrangement in my reply to Mr. Woodhouse.<sup>2</sup> On systems of any size, however, most engineers would hesitate to omit the sub-station high-tension switchgear on account of the trouble which might be experienced if a transformer and a long length of high-pressure feeder were switched in together. Also, where the mains are long, it would be expensive to put in more than two feeders, and the number of transformers in the sub-station would be limited to two, making a rather inflexible arrangement. Mr. Gregory is speaking from experience when he says that any system, whatever its original type, ultimately develops into the more flexible interconnected system, and I think this has proved to be the case on practically all high-pressure networks in this country. Hence it is most desirable to lay out even the smallest system with proper protective gear in the first instance, so that the inevitable interconnection can be carried out with a maximum of security and a minimum of expense. Mr. Williams also emphasizes this point of the flexibility of the interconnected system as against the rigidity of a radial system. Mr. Gregory's remarks on switchgear deserve most careful attention and I am entirely in agreement with them.

In reply to Mr. Carter, vent pipes on switches should have as free a connection with the outside air as possible, but usually it is necessary to cover the opening with a light flap to prevent rain and dust blowing into the switch. The only safe rule for determining the breaking capacity of switchgear (as apart from normal carrying capacity) is to make it capable of breaking the maximum short-circuit current which can be passed by the existing or prospective feeders to the particular sub-station. I have no information which leads me to doubt the permanence of "Pertinax," or other artificial insulation obtained by impregnation with synthetic resins, provided that care be taken in their manufacture.

Mr. Gillott and also Mr. Porter rightly advise engineers to anticipate much larger domestic loads in the future and to lay their plans accordingly. Such developments as they foreshadow should certainly not be tackled by existing methods of low-pressure distribution, and something on the lines of the combined high-pressure interconnected radial systems already referred to will probably prove to be the correct solution.

In switches arranged on the repulsive arc principle the viscosity of the oil and also, as Mr. Tallent-Bateman suggests, to some extent its inertia, certainly prevent the arcs separating as quickly as would otherwise be possible. In spite of this the small mass of the arc allows of a more rapid motion with a given force than is the case with the moving contacts and their operating mechanism. It should also be borne in mind that the lengthening and quickening of the break due to the repulsive arcs are intended to supplement and not to supersede the ordinary break. The repulsive arc arrangement can be applied to a switch without any reduction in the rate at which the contacts

\* Page 387

\* Page 232

Mr. Beard. separate. I agree that to obtain the best results it is preferable to keep each phase in a separate oil tank, and this is desirable for other reasons. At the same time a single tank for the three phases is very convenient and is satisfactory for medium powers. If desired, the phases can be magnetically shielded by steel division plates on either side. I am glad to see it pointed out that many switch failures are due to the external bare terminals being short-circuited by the conducting vapours escaping from the switch after it has broken a heavy short-circuit. This is a point which is still by no means generally realized, although it can be guarded against in the simplest manner by insulating all the leads to the switch.

As regards interlocks, my remarks were principally directed to sub-station switchgear for which Mr. Tallent-Bateman gives them a qualified approval; possibly Mr. Porter's views, which represent the operating engineer's standpoint, may do something to remove the qualification. For power-station switchgear Mr. Tallent-Bateman argues strongly against interlocks, but I am unable to agree with his reasons, many of which could be equally well used against signal interlocking on railways where it is generally acknowledged to be necessary. I have known many mis-

takes made through the use of single-pole isolating Mr. switches, and quite apart from the interlocking question I think the switches on all phases should be operated together. If the isolating switches are mechanically operated from a distance, as they should be on power-station switchgear, no additional insulators are required to couple the phases. Testing should introduce no difficulties, since in a large station testing can be done on the system load, while, if this is not possible, special provision should be made for testing when designing the switchgear. Jumper cables are always undesirable and dangerous. With interlocked screens I imagine a hole would be cut in the screen for such a cable in preference to tampering with the interlocks. Personally I consider interlocks more necessary on power-station switchgear than on sub-station gear, as the effects of a mistake are more disastrous and widespread.

I agree with what Mr. Tallent-Bateman says about potential transformers, but as I stated in my reply to the Manchester Local Section discussion,<sup>\*</sup> my remarks, if carefully read, do not imply special oil switches for them.

\* Page 241.

## DISCUSSION ON

### "THE PRINCIPLES OF MODERN PRINTING TELEGRAPHY."\*

MANCHESTER LOCAL SECTION, 25 JANUARY, 1916.

The meeting was attended by the President, who addressed the members as follows:

Mr. Sparks.

THE PRESIDENT: I propose this evening to speak quite informally. Your Chairman has asked me to make a few remarks with regard to the work of the Institution, but before doing so I want to refer briefly to the difficult question which has confronted the Council in connection with what is called by the man in the street "our alien enemies." There has been a good deal of correspondence in the Press and with the Institution on the subject, and the Council have considered it time after time. Last year, shortly after I became President, we drew attention in the *Journal* to the powers under clause 41 of the Articles of Association. Those powers, as no doubt members are aware, can only be put into effect if 10 members take preliminary action. This month a further note has been published† in which the Council call attention to the fact that we have very ample powers to deal with undesirable members, including alien enemies, and that these powers can be set in force by 10 members. Up to the present no such action has been taken by any members, but in view of the repeated agitation the Council have requested the Committee of Vice-Presidents to consider the whole matter and the Council will take action within the next few days. I cannot state exactly what that action will be, because it

lies with the Council, but speaking as President I can say Mr. that some definite step will be taken.

I think members in Manchester may like to hear what we are doing in London at the headquarters of our organization. First of all we have 52 members of Council, 28 residing in London and 24 in the Provinces. There are no less than 21 standing committees and 9 special committees of the Council. During last year we held 18 Council meetings and 106 committee meetings. I will not take up time by describing the work of all these committees, but I should like to refer to the work of the Research Committee which was appointed three years ago, in connection with which certain sums of money have been voted by the Council for specific researches. During last year the Privy Council appointed an Advisory Council on Research. That Council approached the Institution and asked whether we considered we were doing enough and, if not, what amount of money could be wisely spent on the development of research. A carefully considered report was sent to the Advisory Council dealing with nine heads under which research work should be carried on. Up to now the Advisory Council have only considered two of those heads and we had an intimation last week that they were so well satisfied with our programme that on these two heads alone they were going to give us £1,000 for one year to follow up those two subjects, and there is every reason to suppose that other sums will be voted for

\* Paper by Mr. H. H. Harrison (see page 309).

† See page 308.

additional research. Then we have the Wiring Rules Committee. During the last two years this committee has met 24 times and it has dealt with 500 suggestions put forward by members for the improvement and modification of the Rules. That work is now completed, and the Rules are in the press and will be published within a few weeks. Another committee of importance is the Examinations Committee, and in dealing with that matter I want to point out that, although we have a high standard for examinations, the object of the committee is not to keep out of the Institution people who are really eligible, or to exclude any man of real ability. Those who do not possess the faculty of passing examinations, or cannot find the time to prepare for them, are allowed to enter the Institution if they can pass other tests. We are not trying to set up any academic standard to prevent the right men from entering. During the period of the war the examinations have been suspended where members are on military, munition, or other war service, and the instructions of the Council on the subject will be liberally interpreted. All those men who are giving of their best to their country's cause will be allowed to become Associate Members at the earliest opportunity. Then amongst other standing committees we have the Finance Committee, whose labours are by no means light, especially in view of the financial strain which falls upon this Institution like every other body in this war period, but I am glad to say we are advised by our Honorary Treasurer that our somewhat restricted programme will leave the Institution, even with the reduced income from subscriptions, in a sound financial position. Another committee of very great importance is the Papers Committee, and I know of no section of our work which repays attention to a greater extent than this committee. They are always looking forward months ahead; first of all by asking the right people to write the right class of papers, and then by very carefully examining those papers when they come to hand and suggesting improvements and alterations so as to present them to the members in the best possible form. As regards the special committees, I will only just refer to a few by name, without going into detail as to what has been done; for instance, "Model General Conditions," "Royal Naval Division," and "Model Street Lighting Specifications," etc. I have touched upon the work of the Institution only so as to give members an idea of the magnitude of the duties which fall upon those whom they elect to be Members of Council.

Mr. W. J. MEDLYN: It is an unfortunate fact that many inventors waste time and money in inventing something which has been already tried by someone else. I think there is little excuse for anyone to make such mistakes in the case of printing telegraphs, because in recent years a good deal of useful literature has been published on the subject, partly by means of papers read before this Institution and the Institution of Post Office Electrical Engineers, and partly by means of articles published in service journals of the Post Office and elsewhere. The weaknesses of certain inventions which have failed when put to a practical test have been fully revealed—some of them in the paper now under discussion, and others in articles published by Mr. Donald Murray; and I think that any inventor who desires to introduce a printing telegraph is

now in a position to make himself aware of the principal pitfalls to be avoided. I feel that the publication of such information is of inestimable value in helping forward the development of the system in the general interests of the public service, because, although printing telegraphy has already reached the stage of successful commercial application, certain patterns have only been introduced in very recent times, and I do not suppose that even the inventors themselves who may be concerned in those particular types would suggest that such types are incapable of further improvement, the need for which may be dictated by the results of tests under working conditions. The paper does not lend itself very readily to criticism, or even discussion. Generally, certain facts are explained to us in such a way that they become self-evident, and therefore we accept them without question. On page 315, Fig. 13 shows the time comparison for different telegraphic codes. In Manchester we have the Murray and the Western Electric Company's printing systems, and in Liverpool the Siemens and the Baudot. The Wheatstone automatic and the Creed perforator and printer are also used in both places. On pages 317 and 318, reference is made to the advantages of a reservoir for storing signal permutations as soon as they are set up by the operator in readiness for running through the transmitting apparatus automatically. I should like to know whether the revolving drum referred to has yet been found successful under working conditions, and how many words can be stored in a drum having a diameter of, say, 6 inches. On the Murray and the Western Electric apparatus in Manchester, the operators have no difficulty in typing at the rate of about 50 words per minute and thus keeping well ahead of the automatic transmitter running at 40 words per minute. In Part II the method of type printing is dealt with, but I cannot find that any method of printing a message in duplicate is mentioned. Perhaps the author will tell us whether any such arrangement has been tried, and if so, with what result. In Manchester, specially prepared ink rollers are used, and the printed tape or page print is afterwards run through a copying machine in order that a copy of the message may be retained for departmental purposes. The printing of a duplicate copy by the telegraph apparatus itself would therefore result in a considerable saving if such a device could be introduced. On page 356, the high-speed 1-channel automatic printer is dealt with; that is, we may have four operators each perforating tape at the average rate of 40 words per minute which is afterwards run through the automatic transmitter at the rate of 160 words per minute. I think the general disadvantage of this system, which does not appear to be mentioned by the author, is the delay experienced in obtaining repetitions, or correcting errors of transmission. In the ordinary multiplex system, receiving and transmitting arms are paired together on the table with corresponding pairs at the distant end of the line, and as there is relatively little delay between the perforation of the slip and its passage through the transmitter at either end, questions relating to corrections can be readily asked and answered. In the high-speed automatic system, however, such questions have first to be perforated on one of the sets, and then wait their turn for passing through the common transmitter; and the required reply suffers delay

Mr. Medlyn. for a similar reason at the distant end. As a user of printing telegraphs, I should like to touch upon one important point regarding the maintenance of the apparatus, and that is the ready means which ought always to be provided for repairing or changing defective parts. The apparatus is necessarily complex and some of the adjustments are delicate. It is important, therefore, that all the parts liable to derangement or wear should be easily accessible, and capable of easy removal or replacement without disturbing the adjustment or fixing of other parts. These requirements were not provided for in some of the earlier types, but they have received attention in some of the newer apparatus.

Mr. A. BROOKER: The printing-telegraph practice of the future as indicated by the author is, it seems to me, going to be based chiefly on the work of two men, Hughes and Baudot. The former got over apparently insuperable difficulties by wonderful mechanical devices, and in my opinion he kept printing telegraphs alive by producing, in spite of these great difficulties, a commercial instrument which was used not in this country but very largely in France and Russia for many years. That instrument showed that printing telegraphs could be made commercially successful and sustained and encouraged the work of others. The next and greatest step, in my opinion, was made by Baudot, and I think it will be a long time before we see printing telegraphs without a great deal of the work of Baudot in them. As the paper is more or less historical, I think the author ought to place on record the names of those clever mechanicians who made the ideas of Hughes and Baudot practicable. Those men are quite as deserving of recognition as those whose names are associated with their respective instruments. I am pleased to see the references to Mr. Donald Murray, and I think the Post Office engineers have done most valuable work, though, of course, they have exceptional facilities since all inventors come to them, and they are the only people, at any rate in this country, who can try apparatus under actual working conditions. It is not to be wondered at, therefore, that they have obtained good results, particularly in the duplexing of printing telegraphs. I remember quite well the duplexing of the Hughes instrument; in these days that would not be a very great achievement because lines have improved and many of the problems met with in balancing have been solved, but when it was done it was a difficult task chiefly because the instrument is so constructed that the armature is released by the slightest kick of a current, and the slightest want of balance therefore causes false letters to be printed. I believe that duplexing by the ordinary differential system would have been impossible with a Hughes instrument, but it was eventually done most successfully by using the bridge duplex principle. It was not realized then, and it is not fully appreciated even now, that a differentially-wound instrument, when perfectly balanced to a steady current, is not necessarily so to transient currents, and indeed can hardly be made truly differential to transient currents of different duration and voltage. The Post Office engineers also duplexed the Baudot; that too was a difficult problem, but was rendered easier because many of the troubles had been overcome in previous endeavours to duplex the Delany multiplex. Speaking of that unfortunate instrument on which an enormous amount of work was done,

with not very successful commercial results, it is very gratifying to see from the paper that much of the work which we thought then was wasted has proved beneficial in other directions. Fig. 67 showing the La Cour phonic wheel motor controlled by a vibrating reed is, so far as my memory serves me, identical with the phonic wheel and vibrating reed evolved from the crude Delany apparatus, and it is satisfactory to know that, in the opinion of the author, even for printing telegraphs it cannot yet be beaten. The experience with the Delany multiplex has rather prejudiced many people against the use of a printing-telegraph multiplex system such as the Baudot. The chief reason why the Delany multiplex failed was that the inventor tried an almost impossible task. He distributed the line among four or six operators at regular intervals and those operators were called upon to send, at irregular intervals, signals of a definite length. That, of course, is theoretically impossible to achieve; in practice the signals got through fairly well, but it is absolutely impossible with such a system to obtain perfect signals—some of the dots and dashes must be clipped and others lengthened. The Baudot principle has no such inherent defect, as the operator instead of plunging in just where he likes with a signal, whatever the position of the apparatus may be, can wait for his turn until he launches his signal, with the result that he gets perfect signals through. For that reason I think the Baudot system, in some shape or form, is going to survive. On page 316 the author refers to the well-known cadence signal of the Baudot printing telegraph. The statement that it did not originate with Baudot is rather a shock to me. For many years I have lived under the impression that it did originate with Baudot, and I think the least the author can do is to place on record the name of the originator of such a very important device. On page 310 the author issues a warning to inventors who try to produce signals by varying the strength of the current. I agree with him, but I think it would be as well, in the interests of the inventors, if he would be a little more precise in his warning. Inventors know that telegraph systems relying entirely, or partly, on a variation in the current strength for producing signals have failed, but they also believe that the failure is chiefly due to the fact that those systems have been tried on overhead lines where there has been considerable variation in the insulation. They cheer themselves with the hope that in the next few years practically all the telegraph lines in this country will consist of underground paper-insulated cables. If the author thinks that, even with a perfectly insulated line, methods involving varying currents are not going to succeed, I should be glad if he would make his warning a little more definite and tell us why.

Mr. T. E. HERBERT: There are one or two statements on which I should like a little further information. The author is very clear that the printer which will survive is of the typewriter class. Mr. Donald Murray, it may be remembered, constructed a special typewriter, with a very short type bar, and introduced ball bearings with a view to increasing the rapidity of the machine. The final result, I believe, was that he reached a speed of about 200 words a minute. Now the recent telegraph of Siemens claims a rather higher speed than that, with the aid of a type-wheel. This result may be due to the use of condenser impulses to effect the printing, but I am not convinced that the

typewriter will eventually survive the type-wheel. The author has pointed out that in the simpler forms of telegraph the type-wheel is distinctly to be preferred, and in designing his own machine he has adopted a type-wheel. The machine which the author has devised is suitable for very long distances, but probably it will be rendered more generally useful by the addition of the ordinary typewriter keyboard. There is a simple form of type-printing telegraph (constructed by Siemens) in extensive use in Germany, and it will be remembered that in this country the Steljes apparatus admittedly failed because it was badly constructed; had it been well made it would probably have been in extensive use to-day. It was not, however, and we have never had anything to replace it for short-distance work. The author states very definitely that Morse must necessarily be retained for army purposes. I venture to think that ultimately some form of printing telegraph may have to be devised for use in such circumstances. It is vitally important in the case of Army orders that there should be some definite record of the message transmitted and the message received. The transmission of important instructions over the telephone is distinctly dangerous, and some form of comparatively robust type-printing telegraph would present many advantages. Finally, I am glad to note that the author agrees with Mr. Donald Murray's view that the generation of corrections from the signals themselves is not worth carrying out except on very long circuits.

Mr. T. PLUMMER: Mr. Medlyn referred to the duplicating of messages. In Birmingham—whether it is a new feature of the Department or not I do not know—no copies of the text of messages are now kept. There is only the one copy prepared, which passes on to the public, but certain particulars as to the number of words, address, times, and so on, are recorded on a portion of the form, which can be torn off and retained. The old method of making a copy with carbon paper has apparently been abandoned. This, I think, goes to show that the Post Office is a little more progressive than it usually gets credit for, and if it is now only going to keep a brief record of a message, one of the difficulties which inventors of printing telegraphs have been trying to overcome will have been removed. In Birmingham we have two sextuple duplex Baudot sets working to London, which have taken the place of four quadruplex and four duplex sounder circuits. There is an underground paper-insulated cable between Birmingham and London and these four quadruplex sets were worked on loops, *i.e.* without any earth connection, and on the top of the loops the four earthed duplex circuits were superposed. This old arrangement gave 12 channels working in each direction between the two cities; and those 12 channels, which formerly took up eight wires, are now being provided by two Baudot sextuple duplex sets which only take up four wires. That, of course, brought about a considerable economy in the line circuits, the released wires being available for extension to other towns. A short time ago a trial was made at Birmingham to see what the Baudot sextuple duplex sets could do, and the record between that city and London was 849 messages finished and disposed of in an hour. Even this was not the top figure, because the supply of traffic did not keep up with the speed of transmission.

Mr. G. C. MARRIS: The author has raised several

debatable points, discussing them chiefly with reference to the general principles involved, but they should also be closely considered from the maintenance point of view. When contrasting the single-channel high-speed with the multiplex low-speed instrument, a point that should be borne in mind is the speed at which printed tape can be gummed on to message forms and checked. Gummers and checkers all work in one group with the high-speed instrument and there is only one tape to be gummed. The work can therefore be easily distributed amongst the group and the size of the group varied according to the speed. With a multiplex, however, one gummer at least must be supplied for every channel. The transmitter has to be considered also, and the speed of the channel must be adjusted to give both ends suitable loads. This, of course, is largely a traffic matter. A point of importance from an engineering aspect is the method of power supply. The distributors of multiplex instruments can be driven satisfactorily by weights with motor winding, as in the case of the Baudot. Single-channel instruments, as far as I am aware, require, however, a direct electrical drive, and it becomes of great importance to ensure that a steady and suitable voltage will be available; because, if the pressure is reduced by using resistances in series, the current variations as the instrument works are liable to cause a variation in speed in spite of regulating devices. Another debatable point was referred to by Mr. Herbert, *i.e.* type-wheel versus type-bar printing. I am surprised that the author considers the type-bar printer to be the pattern that will survive, as with its numerous reciprocating parts it is peculiarly liable to breakage. The trouble of breakages is a serious one for the maintenance engineer in all high-speed instruments, and for that reason one cannot help welcoming an apparatus in which a large part of the mechanical work is done by an electrical combiner. An electrical combiner consisting only of relays coupled with a rotating type-wheel offers the best way out of many mechanical difficulties. It is true that a fault in a complicated relay system takes longer to find, but when found it is generally cleared at once. Such relay systems require very little attention. The whole question of the detailed design and inevitable repairs of the mechanical parts of these instruments is one that seems to need further attention. One wonders whether, in their efforts to solve the fundamental principles, inventors and manufacturers have devoted sufficient time to the choice of material. By using special steels with appropriate tempering, the size and weight of many parts might be cut down, with consequent lessening of shock. In that case the question of repairs would need careful consideration. Spares from the manufacturers are not always obtainable, especially in times of emergency like the present, and users should have full information of the right material to be employed in different cases. Otherwise there is a tendency to make necessary replacements from a quality of material, which may serve its purpose but not very satisfactorily. There are a good many mechanical parts that require attention. Breakages occur particularly in the small levers and light, rapidly-moving parts, in springs and in perforated steel plates. Bearings are also a cause of trouble. On some of the modern instruments ball bearings have been introduced and apparently with highly satisfactory results. There is one of the older instruments

Mr. Marris. in particular where a plain bearing is constantly giving trouble through the oil supply failing, and it would appear that a ball bearing there would be a very great improvement. Then there was the question of the material to be used for brushes of the rapidly rotating distributor. A very slight amount of wear on the brushes and segments will cause false signals, and one would think that the kind of material to be used for those parts should be a matter of very careful attention. The author said a good deal about the use of the perforated tape as a reservoir of signals. Although it has been in use for many years, and must no doubt continue to be used, the tape is a very undesirable thing from the point of view of the engineer who has to look after the perforators. The difficulty of making punches do such an apparently simple thing as punch paper rapidly and accurately is surprising. Worn punches and dies are often a source of stoppage; the fault, perhaps, may be in part ascribed to the paper which varies in thickness. At the end of the paper the author refers to Colonel Squier's sine-wave method of telegraphy. One cannot help speculating on the possibilities for printing telegraphy if these methods of "wired wireless" could be successfully applied. One would imagine that all five printing signals might be sent simultaneously on one segment and suitably sorted out at the other end by tuned circuits. With regard to the chain relay system illustrated on page 338, I am not quite able to follow the explanation given by the author. It would appear that the correct reception of a signal depends entirely on the relays having the same speed of operation. There seems to be no guarantee that, say, a marking current from No. 1 transmitting relay will not arrive at No. 2 receiving relay.

Mr. Moore. Mr. G. W. MOORE: The previous speaker remarked that the design of printing-telegraph machines now in use offers scope for improvement from a maintenance point of view, especially with regard to the difficulty in replacing worn or defective parts. This is perfectly true, and in nearly all cases the attention of a skilled mechanic is necessary for the purpose. Having, however, in a minor degree been associated with the author in the development of his printer, the completion of which has unfortunately been retarded due to the present abnormal conditions, I can say that the point raised by Mr. Marris has had full consideration. In fact, the Harrison printer consists of a group of parts, each representing a different function, any of which can be readily detached, and this applies similarly to working parts upon which a fair amount of wear and tear is entailed.

Mr. Latimer. Mr. F. D. LATIMER: I was somewhat surprised to read the author's statement that prior to 1900 only two systems of type-printing telegraphy had achieved permanent success. I think it was in 1872 that the Post Office first granted a licence to the Exchange Telegraph Company to carry on their news-distributing service by means of electrical type-printing machines, and from that time the service has been continuously given. I consider that in a paper dealing with the history and principles of type-printing telegraphs, such as the one under discussion, the name of the late Mr. Frederick Higgins, late Chief Engineer to the Exchange Telegraph Company, should most certainly be mentioned on account of his invaluable pioneer work. Indeed, so far back as 1877 he read a

paper\* before the Society of Telegraph Engineers on the subject of type-printing telegraphs. One of his latter-day inventions was an electrically controlled annunciator which prints in large block letters brief announcements, capable of being read by all the occupants of a large room or hall. Such a device is at the present time utilized in the House of Commons for intimating to those of our legislators who may be engaged in other parts of the building what question is under discussion in the debating chamber. With regard to Fig. 9, it is stated that "at the receiving end of the line the alternating currents pass through a polarized relay L R to earth." This figure depicts a system which is the nearest approach to that of the Exchange Telegraph Company, but in this company's system the relays instead of being at the receiving end of the line are at the central transmitting station, and moreover they are not of a polarized type. Notwithstanding that the relays are not polarized they are sufficiently sensitive to respond to current impulses at the rate of some 2,000 per minute. The author further says: "in series with both the escape-magnet magnets is a printing magnet P M which is relatively slow acting and is unaffected by the stepping impulse." In the system to which I have referred, the electric magnets E M are of the polarized pattern, whereas the printing magnet P M is not. This arrangement assists in securing the requisite slowness of the printing lever; that is to say, as each current impulse is of such short duration as about 0.016 sec., the self-induction of the coils will not allow the current to rise to such a strength as to magnetize the core sufficiently to overcome the inertia of the printing lever before another impulse of opposite direction flows and reverses the polarity. In reality it has been found that when the transmitter motor is running at a speed of 100 r.p.m., the electromagnets in these instruments have a "virtual" or apparent ohmic resistance of approximately nine times their real value as measured on a Wheatstone bridge, and consequently only one-ninth of the current which would be flowing under steady conditions. In conclusion it may be observed that one operator is able to actuate an unlimited number of receiving instruments on any number of circuits from one transmitter, as illustrated in Fig. 9; in fact the Exchange Telegraph Company some years ago maintained about 700 financial recording instruments scattered all over London, which were controlled by one operator stationed at the Central Office in Cornhill.

Professor E. W. MARCHANT (communicated): The printing telegraph has developed very rapidly from the days of the original Hughes apparatus. It is most interesting to find that the 5-unit Baudot system is the one which now seems to hold the field. It is perhaps not very useful to copy German "Kultur," which is now endeavouring to prove that neither Maxwell nor Newton were worth their salt as physicists because they were British, but it is interesting to notice that the inventor of the 5-unit alphabet is a Frenchman and that Siemens and Halske, after spending years on other methods, have had to come back to it. One of the most interesting features in the mechanical construction used in connection with printing telegraphs is the flywheel described on page 343; this device

\* "A Description of the Automatic Step-by-step Type-printing Telegraphic Apparatus used by the Exchange Telegraph Company," *Journal of the Society of Telegraph Engineers*, vol. 6, p. 120, 1877.

should be of value for many other purposes besides telegraphy. The limit of speed of telegraphy is of course determined by the line constants; it is of no use to have a mechanism that will operate at 300 or 400 words a minute when the signal along the line cannot attain sufficient strength to operate the mechanism. This, of course, is particularly applicable to transatlantic signalling. Loaded cables if used in connection with submarine telegraphy should help to improve their working, since the loaded cable does not distort the shape of the current impulse that is being sent, and should enable the receiving apparatus to work more certainly. The ingenious alternating-current system of Colonel Squier is another way of tackling the problem, and since the frequency of the currents is lower than in telephone cables the loading coils could be more widely separated. For the 880-mile cable which he tried, he found the maximum frequency possible was 7, corresponding with a speed of 210 letters per minute, or say 40 words a minute. With a distortionless line it should be possible to improve on this considerably. I doubt whether much can be gained by mechanical resonance with the Squier system, as the impulse for a signal only consists of a half wave of current. The essential feature of an apparatus to work on the Squier system is lightness of the moving parts. The application of type-printing telegraphs to large cable systems is an interesting possibility, and it would seem, in this case also, on general grounds, that the best way to attack the problem is by using loaded telegraph cables. In such a cable all current impulses, of whatever shape or magnitude, are transmitted with the same speed, and it should therefore be possible with such a cable to use successfully the phonic wheel device for the 5-unit Baudot alphabet. The fact that it is better to have special segments on the long Baudot circuits for correcting synchronism is an interesting illustration of the general principle that it is usually best to use any device for the purpose for which it has been designed rather than to make it serve a number of different purposes.

Mr. H. H. HARRISON (*in reply*): Mr. Medlyn says that there is now no excuse for future inventors of type-printing telegraph systems going wrong on fundamentals. In spite of the growing volume of literature on the subject, I think it will be found that fundamentally defective systems will still be proposed if not also produced. There is a partial explanation of this in the fact that a great many printing-telegraph patent specifications are the product of the minds of people having no connection with practical telegraphy. Want of knowledge of the art is very clearly shown by the number of times one sees the same idea re-patented. A very favourite scheme is to employ synchronous distributors with selective means to actuate one of a number of letter-key magnets. The magnets are divided into a small number of main groups, usually four, and these groups are divided into eight sub-groups. Thirty-two characters can be dealt with, but the system requires a 12-unit alphabet. This idea recurs with remarkable persistence. Mr. Medlyn is right to point out that finality in design has not yet been reached. The broad lines have been established, but the cadence and speed-free modern multiplex printing-telegraph has not been employed for a sufficient length of time to enable us to claim finality for details. From experience with two types of mechanical

storage transmitters I am inclined to the opinion that these cannot compete with the perforated-tape combination. It does not seem possible to make such transmitters with a typewriter pattern of keyboard at a much less cost than a keyboard perforator together with an automatic stop-and-start transmitter, and there is the advantage in favour of the latter that the tape furnishes a home record. In my opinion mechanical storage devices will come in for 1-channel manually-worked printing systems, since with a storage of about 12 letters the keyboard is made approximately free. Such a transmitter, of small storage capacity, can be made reasonably cheaply and, as pointed out by Murray, can be used as a retransmitter. The two applications above form its niche. With a 6-in. drum, a transmitter designed by the author stored 25 letters, but in the type of transmitter shown in Fig. 17 the capacity is very much higher. This is possible owing to the fact that as the drum is continually rotated, inertia forces are thus not brought into play, so that the additional loading by storage elements is not detrimental. Taking such a drum of about 1 ft. diameter, 120 letters or 20 words can be conveniently stored. Mr. Medlyn refers to printing in duplicate. A type-bar translator will easily make two or even more copies by the usual manifolding processes, but the ingenious devices for automatically controlling and rejecting the blank must be abandoned. It would appear then that the only practical method of securing an office copy is to use a copying machine. The delay to corrections with an automatic system is well known and is one of the contributory causes to the poor overall efficiency of the automatic system as compared with the multiplex. It is the direct connection of the transmitting and receiving operators, as compared with their indirect connection in the case of the automatic, and the effect this has on the handling of traffic, which are leading all Administrations into the multiplex camp. With the multiplex we have all the advantages of the simple sounder circuit coupled with the complete utilization of the wire capacity furnished by an automatic system. With Mr. Medlyn's remarks as to the design of apparatus so that maintenance is effected as easily as possible, I am of course in accord. I think all designers are seeing to that. One of our anxieties in designing our system at Liverpool has been to make everything easily replaceable and to standardize parts as much as possible, so that we can turn out quantities in bulk and all interchangeable.

Mr. Brooker says that the foundation of the modern printing telegraph is largely due to the work of Hughes and Baudot, and I agree. It must not be forgotten that the Hughes instrument benefited very largely at the hands of Phelps and Froment. Phelps introduced the principle of intermittently coupling the printing to the main driving axle. At the introduction of Baudot's system weight-driven distributors with planetary correcting gear were already in use on the Meyer Morse multiplex, due to Hardy the original constructor of the Meyer apparatus. The échelon method of working suggested by Burnett in 1860 had also been carried into effect by Meyer in 1871. Baudot thus had the previous work of others to guide him; nevertheless we owe him a huge debt. Not only did he show us the best alphabet to use, but he showed us the best way to use it. A great deal of original work, and work which is generally little known, appears in the astonishing number

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of ingenious translators which he invented from time to time. The modern printing telegraph has freely borrowed from Baudot, just as he did from his predecessors, Burnett and Meyer. In saying this no reflection is cast on Baudot. The present is always heir to the achievements of the past. With Baudot the era of achievement commenced, and also one may say that the process of evolution towards the modern cadence and speed-free multiplex printing telegraph set in. Mr. Brooker was surprised to hear that the cadence signal did not originate with Baudot. The cadence signal with locked keyboard developed in two stages. The locked keyboard was first used by Whitehouse in 1854. He provided no cadence signal, but the intermittent locking once per revolution of the distributor brush arm produced a click which would serve to form such a signal. The Baudot form of locked keyboard with separate and distinct cadence signal was first described by Burnett in 1860. Meyer used the cadence signal, but did not lock the keyboard. Mr. Brooker also referred, and rightly too, to the immense amount of work done by Post Office engineers. The Baudot is the only instance, to my knowledge, of a system invented in and developed by an Administration. Every other system has been brought to an Administration by outsiders; and while not suggesting that the trial apparatus is always crude and relatively imperfect, yet in most cases prolonged practical trials under the fostering care of the Administration engineers reveal defects. These officers have not been slow to suggest or even engraft improved details. Two striking instances may be quoted. The Wheatstone automatic can be said to owe its present perfection as a piece of mechanism entirely to the unrecognized work of past and present Post Office engineers. An even more remarkable case is that of the Delany multiplex. A good many of us can remember this apparatus when first introduced and the gradual changes effected before its disappearance—all the work of Administration engineers. The Delany system failed, not for want of engineering skill, but on account of a fundamental defect. We were not so strong on fundamentals in those days. The duplexing of the Hughes, another Post Office achievement, was, as Mr. Brooker says, a difficult task, especially on the lines to the Continent involving lengths of submarine cable. All this work is not so spectacular perhaps as introducing a new "system," but it is solid and enduring. It is a pity that it is not more freely recorded. Inventors proposing to use two strengths of current have nothing to hope for by the extension of underground cables. The alphabet is such that no current is on the line normally, and during pauses in transmission the receiving apparatus, not protected by negative "spacing" current, is liable to interference by inductive effects.

Mr. Herbert is not correct in ascribing a speed of more than 200 words per minute to the Siemens type-wheel printer. The speed is that given in the paper, namely, 1,000 letters per minute. Even at that figure it is a remarkable performance. My advocacy of the type-bar translator is largely on the ground of low first cost. I am afraid that printing telegraphs for military purposes are still in the air. They would have the great advantage that, assuming the employment of the 5-unit alphabet, it would not be possible to "tap" passing traffic, and plain word messages could be employed obviating coding and de-

coding operations. It is not easy to say whether automatic or multiple should be used for military trunk circuits, as the question of portability and table space are matters of some importance in this case. A double duplex step-by-step system can easily be arranged for using either mechanical storers or keyboard perforators and transmitters.

The figures given by Mr. Plummer as to the performance of the sextuple-duplex Baudot sets between Birmingham and London are interesting, but do not give the best possible results attainable by multiple operation. A Murray or Western Union Quadruple duplex would give the same figures with a reduction in operating staff of 33½ per cent.

Mr. Marris remarks that there is only one receiving tape with automatic systems, and that this can be easily distributed amongst a group of gummers at the receiving end of the line. It is the processes of collection of detached tapes at the transmitting end and distribution of receiving tapes, involving as they do the sacrifice of directness of connection between transmitting and receiving operators, which operates so adversely to automatic systems when considered from the traffic point of view. It is just as easy to adjust staff to traffic with a multiplex as with an automatic system. Weight-driven drives may be, and have been, applied to distributor and printer units. The objection to them lies in their weight and under-table space. With phonic-wheel drives to both printers and distributors voltage variation will not be so prejudicial as when shunt-wound continuous-current motors are used. I agree with Mr. Marris that the electrical combiner coupled with a rotating type-wheel is a good arrangement. It is so good that I use it myself, and the performance of the Siemens automatic shows the capabilities of the combination. I do not say that now is the time for the type-bar translator, but unless printing telegraphs come into use by thousands, the type-bar apparatus will compare favourably both in regard to first cost and also, I believe, maintenance. I am, of course, considering its application to multiplex channels where the speed is comparatively low. The class of printer employing type-wheels positioned by differential stop devices will, in my opinion, die out. The parts must be, of necessity, light in weight, and the combined bending and twisting stresses, which are not steady but repetitive and at the fairly high rate of four or five per second, will be found a cause of excessive maintenance. I do not believe any metal can be produced to stand up for any reasonable length of time to these conditions. It is true, as Mr. Marris points out, that the wear on perforator punches is heavy. There is no reason why the dirigeur should not attend to this, and grinding jigs can easily be designed to secure the necessary precision without special skill. I agree with Mr. Marris as to the possibilities of Colonel Squier's sine-wave method of transmission. For land wires the frequencies must be well above telephonic frequencies to avoid possible disturbance. If we go to the other end of the scale, the possibilities of selectivity by resonance are reduced, owing to the shorter time available for "building up." The chain-relay mechanism of Fig. 62 requires the receiving relays to be accurately timed to the transmitting relays so that overlapping of signal elements is not introduced. In later chain-relay methods it is usual

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to provide transfer relays to get over this difficulty. These transfer relays introduce an adjustable time element between each setting relay.

Mr. Latimer takes me to task for not dealing with the work of the late Mr. Higgins. The reason for this lies not in any ignorance on my part of Mr. Higgins's inventions, but rather to the fact that the paper deals with trunk-line telegraphy rather than the distribution of general news and stock-exchange quotations locally in big cities.

I am sorry if I have given Professor Marchant the impression that the 5-unit code originated with Baudot. It was, of course, first employed by Gauss and Weber, and later by Whitehouse. With the Squier system we are not

limited to using only one half-cycle per signal element, but with a loaded cable and employing a frequency of 150 cycles per second a train of oscillations for each signal element may be employed. Mechanical resonance could then be adopted. It must not be forgotten that with this system the receiving apparatus is always moving, and thus there are no starting and stopping influences to be considered. That special correcting segments should always be adopted is by no means the general view. On long lines or cables we have no choice in the matter. Correction from the signals brings complication both in apparatus and adjustment, and if it is unnecessary from the point of view of line time, I fail to see any compensating advantage.

Mr.  
Harrison

## DISCUSSION ON

### "THE WAVE-SHAPES OBTAINING WITH ALTERNATING-CURRENT GENERATORS WORKING UNDER STEADY SHORT-CIRCUIT CONDITIONS." \*

Mr. F. T. CHAPMAN (*communicated*): The interesting collection of oscillograms which the author has published shows that, in spite of the complex form of the resultant field and of the electromotive force in single conductors, the current wave can be regarded, for purposes of calculation, as of sine shape in all practical cases. Hence, when interpreting the results of short-circuit tests, no appreciable error will be made in assuming that the amplitude of the fundamental current wave is  $\sqrt{2}x$  (reading of ammeter) in calculating the armature magnetomotive force. The practical value of the diagrams would have been considerably enhanced if they had been accompanied by the numerical values of currents and electromotive forces, together with some dimensional particulars of the machines. It may be doubted whether a consideration of the limiting forms of the flux-distribution curves is sufficient for a complete analysis of the phenomena involved. The movements of certain components of the field across the pole-face will induce electromotive forces of fundamental frequency in the stator windings, so that these should be grouped with the slot and coil-end leakage and taken into account when estimating the armature reactance. In the case of cylindrical rotors with complete squirrel-cage dampers these field movements will be kept small, but, in the case of machines without dampers and with low normal M.M.F. ratios, the effect may be of sufficient importance to warrant investigation.

Mr. A. R. EVEREST (*communicated*): It might be assumed there would be little advantage in studying the wave-shapes of alternators under the condition of steady short-circuit, since, apart from entirely special applications, machines are not in practice operated in that way. The author has, however, clearly shown this to be a most favourable method of studying the development of har-

monics, since under short-circuit the demagnetizing effect of armature reaction in cancelling the magnetomotive force of the field is at a maximum, bringing into exaggerated prominence the resultant and uncanceled harmonics. It is to be regretted that the paper does not define more explicitly the "winding reactance" or "armature reactance-drop." This is described as including slot leakage and inductance of coil ends. If the slot leakage includes all that flux which enters and crosses the pole-face without threading the pole windings, the total quantity will be consistent with the most popular use of the term; but in this case the values suggested, viz. 5 per cent to 10 per cent winding reactance, would appear to be low for modern machines with a high ratio of armature to field strength. It appears possible, however, that the author intends to exclude from the winding reactance all fluxes entering the pole-face, leaving these to be treated where they properly belong, as combining to cause distortion of the main flux. In this latter case the values for the winding reactance would often be roughly one-half those obtained by the former treatment\* (the actual difference would depend on the design of the particular machine). It is of interest to note the proof that the demagnetizing value of the armature reaction for a 3-phase machine in the position of 90° lag pulsates between the values twice and  $\sqrt{3}$  times the maximum value of the ampere-turns per phase, with a mean value of 1.805 times, as compared with the value 1.5 times which is very generally employed (although the discrepancy was pointed out years ago). One conclusion of particular interest is that polyphase armature reaction in the case of a salient-pole machine may introduce additional harmonics not present in the flux wave, but will not do so in a machine having a cylindrical field.

Mr.  
Everest

\* Paper by Mr. A. E. Clayton (see page 84).

\* A. R. EVEREST: "Some Factors in the Parallel Operation of Alternators," *Journal I.E.E.*, vol. 50, p. 525, 1913.

Mr. Marden.

Mr. W. MARDEN (*communicated*): The author is to be congratulated upon the agreement of his theoretical work with the practical results, as shown on the published oscillograms, and although the condition of steady short-circuit dealt with only occurs at the time of machine test, the investigation is of considerable interest to those responsible for design. The various oscillograms in the possession of Messrs. Siemens Brothers Dynamo Works, Ltd., of which those published are representative samples, fully confirm the wave-shapes predicted by the author, both in respect to current and flux under short-circuit conditions. The alternators with cylindrical rotors for which results are given in the paper are early designs in which the rotors were built up of laminated steel plates threaded on the shaft. On machines of later design with the rotors machined from one steel forging, it is noteworthy that the multi-peak flux-wave (Fig. 17a) still persists, and that there is very little rounding off of the sharp peaks. It is unfortunate that no quantitative results are available, as the author's analysis would then have thrown further light on the magnitude of the losses that are measured under short-circuit conditions. It is evident that the iron loss in the stator may be considerable, particularly on machines of high reactance; and although it is generally accepted that the measured short-circuit losses will vary with the square of the stator current, I am of the opinion that this is not strictly true, particularly for the measurements at high values of the stator current. This would be accounted for on the assumption that a considerable portion of the measured short-circuit loss is due to iron losses, since the exponential of the variation of the iron loss with flux density would be rather less than 2, while the magnitude of the flux wave, although due to the difference of the stator and rotor magnetomotive forces would still be proportional to the stator current. The author's investigation with regard to the flux wave on the single-phase machines under this condition also clearly shows that the large additional losses measured under short-circuit conditions on single-phase machines can be readily accounted for, since the strength of the flux wave and corresponding iron loss on at least a portion of the stator iron can rise to considerable values for machines in which the ratio of stator magnetomotive force to rotor magnetomotive force is not high. In conclusion, the author's graphic methods show the valuable results that can be obtained by a consideration of the spaced distribution of the magnetomotive force of the stator and rotor windings, and although the effect of saturation in the iron parts would have some influence, the method has been utilized with great benefit, particularly in the case of the design of cylindrical rotor machines with which the constant value of the air-gap leads to an easy comparison between the magnetomotive forces at all points of the circumference.

Mr. Clayton.

Mr. A. E. CLAYTON (*in reply*): I am in agreement with Mr. Marden that the conditions of steady short-circuit are of considerable interest to designers. Short-circuit represents one limit of load conditions, open circuit representing the other extreme, and from the study of the behaviour of an alternator under these two conditions—a study easily made in any works—it is possible to predict with sufficient accuracy the performance of the machine under more

normal load conditions, which conditions often cannot be reproduced at the manufacturer's.

Mr. Clayton.

The figure of 5 per cent given for the leakage reactance of turbo-alternators was stated to apply to early machines; for more recent machines the figure of about 10 per cent was intended. The slot leakage was taken as including all the flux that does not link with the rotor winding. The figures given in the paper agree well with those of 7 to 10 per cent given more recently by Professor Walker.\* I agree, however, with Mr. Everest that for large machines with very high armature reaction much larger values than 10 per cent may well obtain. In this connection it must be remembered that considerable difficulty attaches to the determination of the reactance from the measured characteristics. An error of 2 or 3 per cent in the estimated value of the equivalent armature magnetomotive force—a by no means unusual figure—may make a very large error in the deduced value of the reactance. As an instance of the uncertainty there is on this subject it may be mentioned that whereas Professor Walker takes 7 per cent for the reactance drop of a given machine, in the above paper, one of the contributors to the discussion calculates the value as about 16 per cent.

In reply to Mr. Chapman, it would have been possible to resolve the armature magnetomotive force of a single-phase machine into its component harmonics, and to deal with the effects of each separately; but it appears to me that the method outlined in the paper—for dealing with the case in which the secondary actions are negligible—is preferable. By considering separately the dynamic electromotive force due to the rotation of the field winding, and the static electromotive force due to the alternations of the armature magnetomotive force, the simplification is introduced of dealing at the same time with the whole of the components of the latter magnetomotive force. The data available with regard to the oscillograms was not such as to warrant the inclusion of detailed information of the various machines tested.

With regard to Mr. Marden's remarks concerning the iron losses on short-circuit, there is no doubt that these losses may represent an appreciable fraction of the total losses measured under such conditions for polyphase turbo-alternators of high reactance. With single-phase machines the iron losses will be of even greater importance, and it may be concluded that the extra iron losses on load will also be much greater for single-phase than for polyphase machines. Experimental evidence of the fact that the losses on short-circuit vary less rapidly than the square of the current would be interesting, but would require an accuracy of testing far above the average. It is of interest to learn that oscillographic records of tests on machines with solid rotors conform to the wave-shapes predicted. The theory given in the paper holds good for all types of cylindrical rotor construction.

Graphical methods were employed largely by the author, as such methods carry far more conviction to the average designer than those entirely of a mathematical nature, where one is apt to lose sight of physical facts in admiration of the mathematics.

\* MILES WALKER: "Predetermination of the Performance of Dynamo-electric Machinery," *Journal I.E.E.*, vol. 54, p. 257, 1910.

## INSTITUTION NOTES.

## ROLL OF HONOUR.

## (SECOND LIST.)\*

## MEMBER.

<i>Name.</i>	<i>Corps, etc.</i>	<i>Rank.</i>
<i>Died.</i>		
Seligmann-Lui, G. P.	French Military Telegraphs	Director

## ASSOCIATE MEMBERS.

<i>Killed in Action.</i>		
Davison, H. J. G.	1st Lancashire Fusiliers	2nd Lieut.
Hoyle, E.	Honourable Artillery Company	Sergeant

<i>Died of Wounds.</i>		
Bradbury, G. S.	6th Manchester Regt.	Sergeant

## STUDENTS.

<i>Killed in Action.</i>		
Forbes, J.	Royal Engineers	2nd Lieut.
Hunt, F. E.	Sussex Yeomanry	Trooper
Thornton, J. M.	Royal Engineers	Lieutenant
<i>Died of Wounds.</i>		
Hill, C. H.	16th Canadian Infantry	Private

## ORDINARY MEETINGS OF THE INSTITUTION.

The arrangements for the remainder of the session are as follows:—

9 Mar.	E. V. Pannell	"Continuous-current Railway Motors."
16 Mar.	N. W. Storer	"The Use of Continuous Current for Terminal and Trunk-line Electrification."
13 Apr.	Discussion on	"The present position of Electricity Supply in the United Kingdom; and the steps to be taken to improve and strengthen it after the War."
11 May	Annual General Meeting.	

## LONDON ELECTRICAL ENGINEERS.

The Secretary has been asked by the Officer Commanding the London Electrical Engineers again to call attention to the fact that there are vacancies in this Unit for qualified electrical and mechanical engineers. Full particulars will be found on page 308 (No. 255).

\* See page 64.

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2, Minutes of evidence, etc.

3, Records of observations in factories.

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# THE JOURNAL OF The Institution of Electrical Engineers

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No. 258.

## CONTINUOUS-CURRENT RAILWAY MOTORS.

By ERNEST V. PANNELL, Associate Member.

*(Paper received 8 November, 1915; read before THE INSTITUTION 9 March, and before the MANCHESTER LOCAL SECTION 22 February, 1916. In view of the author's absence in Canada, the paper was read on his behalf by Mr. Roger T. Smith, Vice-President.)*

### INTRODUCTORY.

It should be explained at the outset that the title of this paper is intended to cover some interesting features in the design of continuous-current motors for railway motor-car operation. The design of locomotive and alternating-current motors, whilst offering much that is of interest, is too wide a subject to be dealt with here. Few forms of electrical machinery have seen more rapid and efficient development than the traction motor; in little more than 20 years it has grown from the open-type, double-reduction machines of Sprague, Short, and Vandepoele, rated at about 10 to 15 kw., to the compact, ventilated, interpole 200-kw. motors in common use on our underground and suburban railways.

The year 1895 saw practically the end of the "trial and error" stage of electric railway engineering, and the establishment of a common basis of design for railway motors. This comprised 4-pole structures of waterproof design, series excitation, drum armature-winding, usually of the 2-circuit type, and a speed at rated load of about 500 r.p.m., thus permitting of single-reduction gearing. Developments of more recent date, however, offer much that is of interest to the designer and user of electrical machinery.

The study of the railway motor can best be approached by a brief survey of the requirements of such a machine. The widest field for electric traction in densely populated countries like Great Britain and the eastern United States is for urban and suburban railway service in the industrial areas. Typical average conditions for such a service are the running of trains of 150 tons weight at a schedule speed of 16 miles per hour, with two stops per mile. Such a train would conceivably have five cars, the front and rear ones carrying motors and weighing 40 tons each, fully loaded, whilst the remainder would be trailers. The service would call for an average initial acceleration of at least 15 miles per hour per second, necessitating an aggregate tractive effort at the wheel-treads of 23,000 lb. Now, as the weight per axle of the motor-cars is only 22,400 lb., the maximum tractive effort per axle with a

friction coefficient of 0.2 would be 4,480 lb. The most usual motor arrangement would consist in driving every one of the eight motor-car axles; each of the motors would therefore have to exert a tractive effort of about 3,000 lb. If the train be accelerated up to 15 miles per hour on the rheostats the output of each motor during acceleration would be 90 kw., and this figure would in all probability approximately represent the rated capacity of the machines on the 1-hour basis. Alternatively, the weight of the motor-cars might be so distributed as to throw a greater proportion upon the leading trucks, and two motors per car, each motor rated at 180 kw., be employed.

The foregoing are typical straightforward conditions of electric suburban service; in many circumstances, however, the requirements are of a much more onerous nature. Electric traction has to contend with heavy grades, short-radius curves, subaqueous tunnels, heavy rush-hour and excursion overloads, and often unskilled operation. Motor-cars are frequently kept in practically continuous operation for from 18 to 20 hours per day. The railway motor is therefore a piece of machinery liable to very severe usage, and its design and construction in accordance with its service conditions form an interesting study.

Throughout the paper the following assumptions apply:—

(1) The rated output is the power delivered through the gears according to the standard 1-hour basis of rating (see Appendix).

(2) Power throughout the paper is defined in kilowatts, the horse-power unit for motor rating being considered obsolete.

(3) Voltage, except where otherwise specified, is assumed to be 600.

(4) Rated speed or rated current is the speed or current corresponding to the rated output, as in (1).

(5) The object of the paper being to consider general tendencies in design, the curves and tables should be regarded as representative of such tendencies rather than of precise quantities.

## WEIGHTS AND DIMENSIONS.

In the last few years, owing partly to the competition of the alternating-current motor, but more to the widespread demand for increased economy in all branches of engineering work, considerable improvements have been effected in the design of the traction motor. Figs. 1 and 2 show one direction in which this improvement has been manifested. The dotted curves represent the average weight in pounds (including pinion, gear, and gear-case) of the railway motors in general use up to about the year 1909, whilst the full lines show the weights of motors of similar output designed since this date and in operation

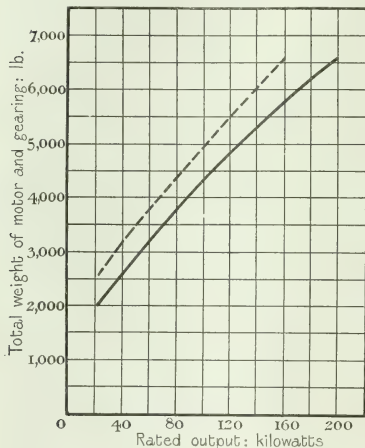


FIG. 1.—Weights of continuous-current railway motors at 600 r.p.m. rated speed.

Broken curve : designed before 1909.  
Full curve : present-day designs.

to-day. These latter, it is interesting to note, are almost all of the commutating-pole type.

In all parts of electrical railway equipment dead-weight is an objectionable feature, and nowhere more so than in the motors where these are suspended directly upon the trucks. The nose form of suspension in general use throws about half the weight of the motor upon the axle without any intervening springs; and owing to the thrust of the gears this proportion is increased or diminished during acceleration according to the position of the motors. Moreover, owing to the motor armature rotating from three to four times as fast as the wheels, the energy stored up in it during the accelerating periods will be very considerable, and for this reason minimum weight and armature speed are desirable. A typical calculation for the value of this momentum has been worked out by Mr. F. W. Carter.\*

\* *Journal I.E.E.*, vol. 50, p. 437, 1913.

The following figures are of interest as showing the weights of two motors of identically the same rated output at 500 volts. The GE 74 machine was, however, introduced in 1904 and the GE 201 in 1910.

Type of motor	GE 74	GE 201
Rated kilowatts	48	48
Weight ; motor without		
gears	3,119 lb.	2,385 lb.
armature and pinion	845 "	639 "
gears	240 "	220 "
gear-case	175 "	130 "
motor and gears complete	3,534 "	2,735 "
per kilowatt rated output	74 "	57 "

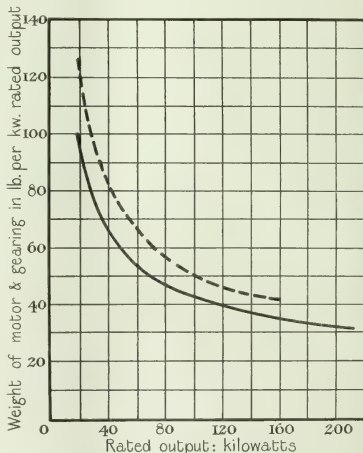


FIG. 2.—Unit weights of railway motors corresponding to Fig. 1.

This reduction of nearly 800 lb. in weight has been secured partly by the increase of rated speed made possible by the adoption of commutating poles, but to a greater extent by the use of more carefully chosen material of higher weight efficiency and a ventilated structure. The rated output given above does not by any means represent the service capacity of the two motors, since owing to its ventilated design the GE 201 motor will have a sustained capacity not less than 50 per cent in excess of that of the older type of machine.

A closer investigation of the curves in Fig. 1 will show the desirability, from the weight-efficiency point of view, of employing a few motors of high capacity, rather than a greater number of low capacity. Let us consider alternative arrangements for the equipment of a train of six

cars, two of which are motors. Service requirements necessitate the expenditure of 720 kw. at the wheel-treads during acceleration, and this may be accepted as representing the aggregate rated output of the motors employed. The two alternatives are:

	I	II
No. of driving axles ...	8	4
" motors ...	8	4
Rated kw. per motor ...	90	180
Weight per motor ...	4,000 lb.	6,200 lb.
Cost per motor ...	£230	£340
" total ...	£1,840	£1,360

It need hardly be said that conditions occasionally dictate the adoption of Alternative I, but, *ceteris paribus*, it may be affirmed that the best practice is to employ the

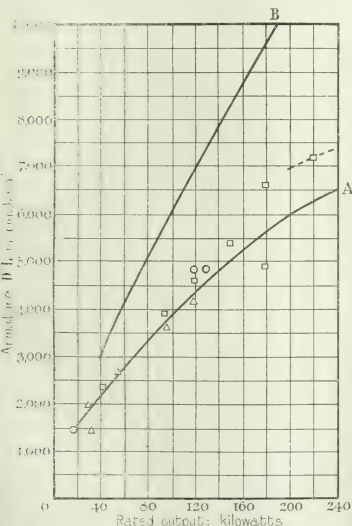


FIG. 3.—Relation of output to dimensions of armature.

Curve A—Geared railway motors, 600 r.p.m.  
 " B—Hobart's curve for c.c. machines, 600 r.p.m.  
 ○ indicates British, □ American, and △ Continental designs.

largest motors which can be economically loaded on the lightest service. Rheostats, contactors, reversers, and train cables require to be duplicated for every additional pair of motors; the above disparity in costs would therefore be far greater were the complete equipment included.

Turning to the question of linear dimensions, it is found that the limitations in this direction are of even more strict a nature than those governing the weight. On

the standard rail-gauge of 4 ft. 8½ in. the maximum distance between the inside of the wheel flanges is 52 in., which of course positively limits the length of the motor casing. In the other direction the wheel diameter is the limiting feature, and in view of the minimum structure gauge, height of station platforms, and head clearance within the cars, a wheel of greater diameter than 36 in. has seldom hitherto been tolerated, and as a matter of fact the size in common use on by far the majority of electric suburban, elevated, and subway railways is 33 in. However, it is interesting to note a recent more liberal tendency in this direction, and there is no doubt that wheels of 36 in. to 42 in. will become standard except where tunnel limitations are too severe. With the 33-in. wheel the radial distance corresponding to the armature radius, air-gap, length of pole-piece, and thickness of motor shell, is obviously something less than 16½ in., which gives a maximum armature diameter of 20 in. The axial length of the armature core is still further restricted owing to the fact that with increasing output more lateral space is demanded for the gears and commutator; this leaves about 15 in. as the maximum practical length of core between end plates for a 600-volt motor of about 200-kw. rated capacity.

In most classes of electrical machines a fairly close relation can be established between the size of armature and the output, and in Fig. 3 an attempt has been made to represent the law as applied to traction motors on the 1-hour rating. Curve A represents a series of interpole designs worked out by the author, whilst the points indicated refer to machines in actual service from which the constants have been derived. As will be seen, British, American, and Continental designs are included, and the agreement is fairly close. The step at the end of the curve relates to motors with duplex gears, this being an expedient adopted with machines of very heavy output at a fairly low speed. The torque being too great to be satisfactorily transmitted through one pinion, gears are mounted at either end of the motor shaft; this necessarily narrows down the axial length of frame and armature core, therefore calling for a greater armature diameter.

Motors of this size and type are of interest, however, only for locomotive work and are therefore outside the scope of this paper. It is interesting to compare the curve relating to railway motors with that plotted for stationary machines; the great disparity is of course due mainly to the system of rating employed.

#### SPEED AND TRACTIVE EFFORT.

Railway motors, being invariably series wound, attain high rotational speeds at light loads. The free-running speed in service usually coincides with about one-third the rated load, and is nearly double the rated speed. In other words a motor having an armature diameter of 20 in. and a rated load speed of 600 r.p.m. would attain a rotational speed of about 1,000 r.p.m. and a peripheral speed of 5,250 feet per minute when free running. With higher degrees of saturation the increase at light load will not be as great, but in any event it will be very near the maximum judicious peripheral velocity. This, together with the fact that the gear and friction losses are greatly increased at high rotational speeds, provides an argument

against the use of higher rated speeds than 600 r.p.m. Indeed this figure may be said to cover practically all types of motor for car operation other than those designed for control by sectional fields. Consideration of the proportionment of losses in the machine may, as will be seen, sometimes dictate the use of a somewhat lower or higher speed for certain types of service, but 600 r.p.m. is a good average value for satisfactory designs. The main disadvantages of extreme speeds may be indicated as follows:—

<i>High Speed.</i>	<i>Low Speed.</i>
High core and friction losses.	High copper losses.
Excessive forces on armature.	Excessive pinion stresses.
Faulty commutation.	Poor ventilation.
	Heavy machine.

In general the efficiency of the high-speed motor is better at rated load and inferior at light loads as compared

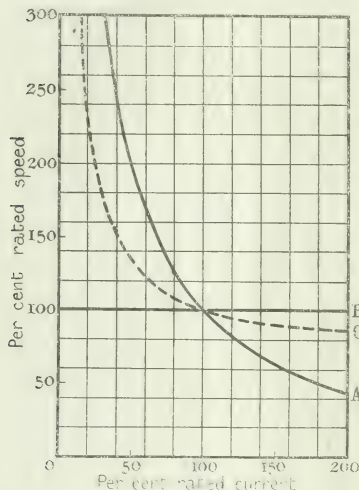


FIG. 4.—Speed curves.

- (A) Limiting minimum saturation.  
(B) Limiting maximum saturation.  
(C) Typical 175-kw. railway motor.

with the lower-speed design. In the former motor the core and friction losses are higher and the copper losses, owing to the fewer armature turns, are less; this in a measure discounts the high-speed motor for service involving much high-speed running. On the other hand the lower-speed motor having a higher armature resistance will be less desirable for work involving frequent accelerating periods at the full rated current; it will

operate with higher efficiency on long straightaway runs with few stops.

The influence of the form of saturation curve upon the motor characteristics has been well illustrated by comparison with curves showing the hypothetical maximum and minimum degrees of saturation.\* Figs. 4 and 5 indicate the typical speed and torque curves for a large railway motor compared with similar characteristics of a theoretical machine with maximum saturation in which the field flux is constant, and also of a motor in which the saturation is nil, the flux increasing as the square of the current. It will be seen that the actual practical design tends towards one or other of these extremes according to the service for which the motor is designed. For long runs without stops where time has to be maintained in spite of adverse conditions, the motor showing the least variation in speed for a given difference in torque, in other words the highly saturated motor, is desirable. On the

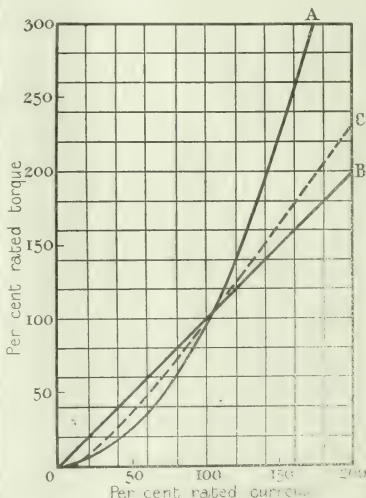


FIG. 5.—Torque curves.

- (A) Limiting minimum saturation.  
(B) Limiting maximum saturation.  
(C) Typical 175-kw. railway motor.

other hand, for services with frequent stops, involving rapid acceleration, a fair proportion of the running will be upon the motor speed-curve, which needs therefore to be of the flexible type, characteristic of a machine with a less highly saturated magnetic circuit. The saturation curves of four motors in very extended use comprising two different makes are shown in Fig. 6.

\* PARSHALL and HOBART: "Electric Railway Engineering," p. 58.

It should be noted that the motor losses will influence the characteristics, copper losses tending to reduce the speed and core losses to diminish the torque.

#### COMMUTATING POLES.

From the nature of its design the continuous-current traction motor must be expected to commute poorly, compared with stationary machines of similar output and voltage. In generator design it is usual with increasing output to increase the number of poles and of parallel paths through the armature in order to improve the collection of current. These devices are of course inapplicable in the case of traction motors on account of the confined space; the armature size is limited and the number of poles is restricted to four. Moreover, in order to balance out inequalities in the air-gap and to permit of operation with only two brush sets, the 2-circuit winding

brush studs and still to maintain sufficient spacing to guard against flash-overs; moreover, the increased friction and heating offset the improvement (if any) in the commutation.

A device which has found universal adoption is the grooving out of the commutator mica to a depth of about  $1/16$  in. below the surface of the copper. This avoids any trouble due to high mica and has a remarkable effect in keeping the commutator surface clean and cool. Soft brushes are of course never employed with this type of machine, and with the hard carbons in common use centrifugal force is found quite sufficient to keep the slots free from particles.

In the early days of electric railways certain Sprague motors were designed with compensating windings to neutralize the armature flux, but the commutating pole proper was not commercially applied to traction motors until the year 1905. At this time interpole motors rated at 100 kw. were put into operation on the 1,000-volt continuous-current railway running from Cologne to Bonn. Two years later a similar type of motor was placed upon the market in the United States, although it was not until the year 1908 that any of these American-built machines were advertised as being applicable to pressures much in excess of the standard 600 volts. Now, however, commutating-pole motors are being regularly supplied with 2,400-volt insulation and 1,200-volt commutators for running two in series on a 2,400-volt line. The broad advantage obtained by the use of interpoles is the greatly reduced chance of flash-overs. The reactance voltage being practically neutralized and the sparking proportionally lessened in severity, there remains little to start an arc from brush to brush or to frame. The commutating-pole machine therefore becomes a stronger type of motor, capable of heavier short-time overloads and higher speed and voltage, whilst its maintenance charges are greatly reduced.

An important influence of the commutating pole upon the design of the motor is the increase of the armature and decrease of the field component in the same proportion. To accommodate the interpole the neutral zone has to be slightly widened and the polar arc shortened; consequently the total flux entering the armature from the main pole is reduced to a corresponding degree. On the other hand the reduced armature reaction permits of an increased loading in ampere-turns on the armature. Moreover, although it has been urged by some designers that the commutating pole could never be introduced into railway motors on account of the confined space, it is found that the traction motor is no larger and, as already seen, is lighter than the pre-interpole machine. A notable instance of the use of the commutating pole in a motor of extremely limited size is found in the machines on the Moselhütte mineral line in Lorraine, where the locomotives are operated at 2,000 volts, the pressure on each motor being 1,000 volts. The gauge of the line is only  $30\frac{1}{2}$  in., notwithstanding which it has been found possible to equip the locomotives with motors rated at 120 kw., the armatures being of 26 in. diameter with a core length of only  $6\frac{1}{4}$  in.

Table 1 gives the outline design features of typical modern commutating-pole railway motors for 600-volt operation.

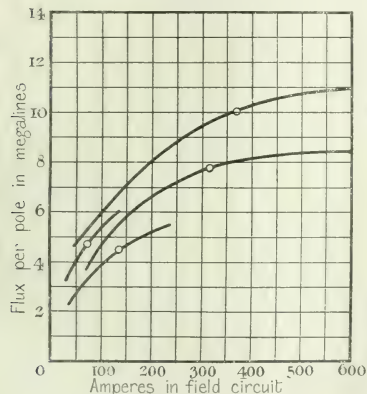


FIG. 6.—Saturation curves for railway motors.

The circles denote rated currents.

is universal. Practically all motors of 100 kw. and over are designed for one armature turn per segment in order to reduce the reactance per coil, but until the general introduction of commutating poles no other device could be adopted excepting the maintenance of a well-saturated magnetic circuit, a wide neutral zone, and the lowest practicable commutator speed. Even with motors of the most careful design and construction the reactance voltage at rated load is of the order of 9 or 10, or four times that of a reasonably good generator. Certain motors have been designed with four brush sets, mainly with the idea of shortening the commutator and providing more space for the armature core. It has been found difficult, however, to secure adequate space for the four

## FIELD-CONTROL MOTORS.

As already seen, although 600 r.p.m. represents the average speed at rated load of by far the majority of satisfactory designs, there are occasions where some variation of this quantity is desirable. It is frequently the case that a certain type of motor being standardized by a railway company will be called upon to perform widely different classes of service, possibly interchanging

have at its full field a speed 10 per cent lower than the average machine, whilst with the short field this speed is increased by some 25 per cent. The motor is thus able to run upon either of two speed curves at the will of the motorman.

Sectional field control was used on some of the very early motors, but the method later fell into disuse and it was not until the general adoption of the commutating pole that field control was definitely established. With-

TABLE 1.

*Outline Data for 600-volt Interpole Railway Motors at 600 r.p.m. Rated Speed; Non-field Control.*

Rated output, kw. ... ..	25	50	100	150	200
Efficiency, per cent ... ..	84	86	89	90	90
Input, kw. ... ..	30	58	113	167	222
Ampères ... ..	50	97	189	278	370
Armature turns ... ..	444	320	234	195	170
Ampere-turns ... ..	11,000	15,000	22,000	27,000	31,000
Flux per pole, megalines ... ..	3.4	4.9	6.5	7.8	9.0
Turns per segment ... ..	3	2	1	1	1
Commutator segments ... ..	148	160	234	195	170
Armature slots ... ..	37	40	30	39	34
" diam., in. ... ..	14.5	16.0	18.0	19.0	20.0
" core-length, in. ... ..	8.0	9.8	11.7	14.0	14.5
" D <sup>2</sup> L, in. ... ..	1,700	2,500	3,800	5,000	5,800
Weight, lb., less gear ... ..	1,980	2,540	3,060	4,050	5,050
" with gear ... ..	2,200	2,800	4,400	5,500	6,600

TABLE 2.

*Outline Data for 600-volt Interpole Railway Motors at 600 r.p.m. Rated Speed; Field Control.*

Rated output, kw. ... ..	25	50	100	150	200
Efficiency, per cent ... ..	82	84	88	88	88
Input, kw. ... ..	31	60	114	171	228
Ampères ... ..	52	100	190	286	380
Armature turns ... ..	480	336	258	215	186
Ampere-turns ... ..	12,600	17,000	24,200	30,400	35,200
Flux per pole, megalines, full ... ..	4.1	5.9	7.8	9.4	10.8
" short ... ..	3.1	4.4	5.9	7.1	8.1
Turns per segments ... ..	3	2	1	1	1
Commutator segments ... ..	160	168	258	215	186
Armature slots ... ..	40	42	43	43	31
" diam., in. ... ..	15.0	17.0	19.0	20.6	21.8
" core-length, in. ... ..	9.2	10.5	12.6	14.0	14.5
" D <sup>2</sup> L, in. ... ..	2,040	3,000	4,550	6,000	6,900
Weight, lb., less gear ... ..	2,380	3,050	4,750	5,950	7,100
" with gear ... ..	2,640	3,400	5,280	6,600	7,900

local service with as many as two stops per mile, with express schedules running five miles or more without a stop. For the local service, high-speed low-copper-loss motors are required having a low-speed gear; whilst the most suitable machines for the fast service are those rated at a lower speed and having a low core loss and high-speed gearing. The use of sectional or tapped field control affords one method of effecting the compromise and operating a system of diverse characteristics with one type of motor. More valuable still is the use of field control for notching up on the controller during acceleration. A motor designed for this principle will probably

out interpoles, as may be imagined, weakening the field causes excessive rushes of armature current, sparking, and flashing over. To a small extent these troubles in earlier motors of the type were due to the shunting of a portion of the field winding rather than to its being open circuited. Such a procedure naturally increased the lag of the field current, opposing the growth of the flux, and serious sparking was the result. The commutating characteristics are so improved in the interpole machine, however, that reduction of the main field by 50 per cent does not appear to affect the collection of current. Typical speed curves for a field-control motor are shown in Fig. 7.

The "full field" characteristic of a motor of this type should be a good flat curve, denoting extremely high saturation, otherwise the "short field" curve will show dangerously high speeds at light load: 450 r.p.m. for the rated load speed at full field, and 550 or 600 at short field, are typical of what has been found most satisfactory practice for a 200-kw. motor. Too great a disparity in the speeds at any given armature current leads to a pronounced current "kick" when changing, and would probably tend to induce flashing over.

To those accustomed to laying out performance curves for electric railway equipment it is sufficient to say that the field-control motor provides a shorter rheostatic period and a much longer period of motor speed-curve running. The lower the full-field speed of the motor the quicker will the rheostats be cut out, and the less the rheostatic losses for a given acceleration rate. On one

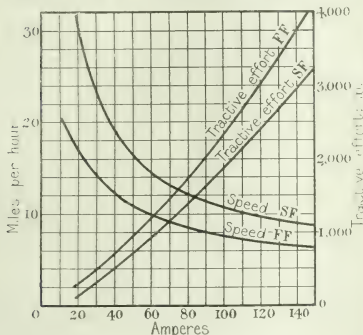


FIG. 7.—Speed and tractive-effort characteristic for a 45-kw. motor on short (SF) and full (FF) fields.

of the suburban railways in Christiania, Norway, the field windings of the 1,200-volt motors are not only divided for short and full fields, but are grouped for series and parallel connections. This gives four different running speeds all with the motors directly on the line. By this means nearly half of the controller notching may be performed free of rheostats, and a good approximation to alternating-current tapped-transformer control is effected. The mere tapping-off from a single point near the middle of the field winding is becoming standard practice, however, in view of the simplicity of the necessary controller connections.

#### RATING.

Under this heading are discussed the associated subjects of efficiency, losses, and heating.

The output of a railway motor is based upon a certain definite temperature rise under certain definite conditions. This rise is closely related to the watts lost in the motor and to the effective dispersal of these losses. At the present day there are three general types of motor in use, namely, (a) enclosed, (b) ventilated, and (c) forced

draught; but on the usual 1-hour rating these are all brought into line, as by common consent no kind of forced ventilation is permitted for the 60-minute heat run.

The overall efficiency of a motor allows for losses in the copper, core, and commutator, together with gear and bearing friction and windage. As factors in the temperature rise, however, all but the gear losses are effective. In the short 1-hour heat run these are absorbed

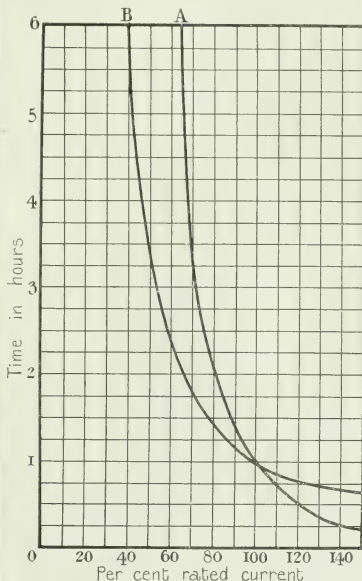


FIG. 8.—Time taken to attain 75 degrees C. temperature rise on hottest accessible part.

(A) Ventilating (B) Non-ventilating motors

in the mass of the machine, there being little radiation with heavy motors; it is therefore justifiable, as proposed by Mr. H. M. Hobart,\* to assign a certain definite value of kilowatts per ton weight of motor for the 75-degree C. temperature rise. This "kilowatts per ton" expression is, however, one of a very approximate nature and useful only when comparing motors of similar type, size, and ventilation characteristics. This relation of the losses to the mass of the machine shows that the weight cannot be reduced to a radical extent without also designing for an increased efficiency, and that a low-efficiency motor is *ipso facto* a heavy one for its output. The output

\* "Heavy Electrical Engineering," chapter 11, p. 245.

of a railway motor at rated load is, however, being superseded as a criterion of its service capacity. What is far more important than the 1-hour rating is the capacity for continuous operation of five or six hours or even longer periods.

The curves in Fig. 8 throw some light on this point, and referring to these it will be seen that although two different machines may have exactly the same rated 1-hour output, efficiency, and possibly weight, their performance on runs of longer period is radically different. Motor A, it will be seen, will take much heavier loads to reach its

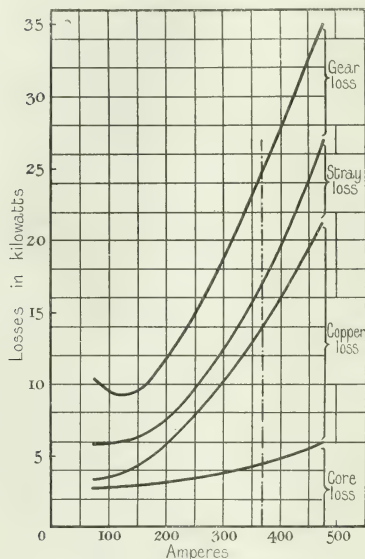


Fig. 9.—Losses in a 180-kw. motor.

75-degree C. rise than motor B for two, three, or four hours' running. The former is representative of the recent ventilated designs, and the latter of the totally enclosed carcase motors which are only just being superseded by type A. It may be urged that 75 degrees C. is an undesirably high temperature rise for a service condition, even for an 8-hour run, but it will be noted that the curves shown relate to stand tests, and the heating in actual service may be assumed to be some 15 per cent lower on account of the positive draught produced by the motion of the train.

Actual service, however, does not demand a steady current input, but a very fluctuating one, the values of

which can only be predicted by graphical construction of the speed- and current-time diagrams. The voltage too is a variable quantity, taking into account the number and duration of the stops, coasting periods, etc. It is obvious that the heating, so far as it is influenced by the copper losses, depends upon the square root of the mean of the squares of the varying current input. Further, the core losses are directly proportional to the product of speed and flux, or, in other words, approximately to the impressed voltage. Determination of the R.M.S. current and average voltage from the performance curves will therefore afford a clue as to the average losses and thermal capacity of the motor.

In Fig. 9 are shown the approximate values of the losses in a 180-kw. railway motor, and Fig. 10 shows the thermal characteristic of the same machine running on stand test. The preponderating factor in the temperature rise at rated load is the copper loss, and at light loads the core and

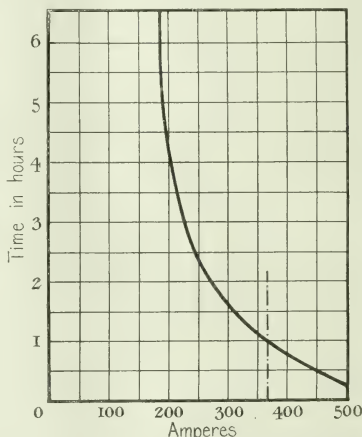


Fig. 10.—Thermal characteristic of 180-kw. motor (see Fig. 9) for 75 degrees C. temperature rise.

stray losses; consequently a motor for frequent stops and accelerating service should be designed with a view to the lowest possible copper loss, whilst the machine which is expected to run for one or more hours continuously at about one-third rated load should have the lowest possible core loss in order to operate within its temperature limitations. For a given speed, low copper loss implies an armature winding of few turns, and consequently a high value of polar flux, which in an armature of given size leads to an increased core loss. At the same time the higher field excitation may lead to a disproportionately increased P.R. loss in the field windings if pushed too far. In many cases better practice is followed

by increasing the rated speed in inverse ratio to the armature turns; thus the pole flux is unchanged, the armature I<sup>2</sup>R loss is diminished, and the core loss is increased almost in direct proportion to the augmented speed.

The foregoing considerations show that it is impossible to specify for a railway motor on the basis of its 1-hour rating alone. Specifications should call for the value of the various losses at two or three different loads, particularly for the average load at which the motor is expected to operate in service.

Reference to Fig. 9 will demonstrate that copper and core losses are far from being the only losses of significance. The stray losses due to journal and commutator friction and windage are all factors in the tempera-

#### VENTILATION.

Reverting to the curves in Fig. 8 and bearing in mind the fact that the average load on a railway motor is from 25 per cent to 45 per cent of its 1-hour rating, the value of the present ventilated designs is fully evident. In more than one instance on electric railway systems in America, ventilated motors rated at 50 kw. are doing the same work as the 80-kw. non-ventilated machines which they have superseded, with a net saving of 50 per cent on the equipment weight and of 30 per cent on its cost. Contrary to general opinion ventilated motors have been found to operate satisfactorily even under the most adverse circumstances of dusty and gritty ballast.

One of the first types of semi-ventilated motor in general use in England was the GE 66, 95-kw. motors

TABLE 3.

*Data of 600-volt Continuous-current Railway Motors in Actual Operation.*

Motor		Output		Weight. Lb.			Speed r.p.m.		Saturation Factor	Efficiency. %		Operating on
Ref.	Type	h.p.	kw.	Less Gear	With Gear	Per kw.	Rated Load	1/3 Rated Load		Less Gear	With Gear	
A	GE 203	50	37	2,170	2,640	72	630	1,140	1.80	89	85	Twin City Rapid Transit, Minn.
B	W 306	60	45	2,645	3,030	67	625	1,150	1.85	89	85	Pacific Electric RR., Cal.
C	GE 201	75	50	2,385	2,735	49	680	1,120	1.65	89	85	International Ry., Buffalo [Ia.
D	W 321	90	67	3,680	4,150	62	530	970	1.83	89	85	Waterloo and Cedar Falls RR.,
E	GE 205	100	75	3,230	3,700	49	750	1,300	1.73	90	86	Oregon Electric Ry.
F	GE 60	125	94	3,900	4,400	47	550	980	1.78	91	88	Central London Ry.
G	DK 4A	160	119	6,050	6,535	55	470	970	2.06	91	88	Lancashire and Yorkshire Ry.
H	GE 55A	160	119	5,000	5,415	41	530	880	1.05	89	86	Boston Elevated RR.
J	GE 248	160	119	5,400	5,975	50	550	1,230	2.23	90	87	New York Municipal Ry.
K	W 86B	200	150	5,500	6,200	41	650	1,090	1.68	91	88	New York Subway
L	W 308	225	170	6,150	6,740	40	590	960	1.72	91	88	Southern Pacific RR., Cal.
M	GE 60	240	180	5,400	6,000	33	540	930	1.72	91	88	London Electric Ry.
N	W 339	275	205	7,000	7,800	38	570	900	1.58	92	89	L. & S.W. Ry.

All the above are commutating-pole motors with the exception of F, G, H, K, and M. Motor J is a field-control design having a full field 25 per cent in excess of normal, hence the high saturation factor. This latter quantity is a figure denoting the shape of the speed curve, and is the ratio of the speeds given in the two previous columns.

ture rise, whilst the gear friction detracts a further 3 per cent to 7 per cent from the efficiency according to the speed.

The basis of both the American and European methods of rating railway motors is the 75-degree C. temperature rise in a 1-hour run on the test bed with covers removed and no artificial ventilation. Without having been standardized in England this system is in very general use here and might quite well be officially adopted. It is usually recognized that the 1-hour rating represents the maximum desirable current input for acceleration, and that the average load for a complete day's running should not exceed 30 per cent rated load for unventilated, or 50 per cent rated load for ventilated machines. A tendency is at work to assign a standard for continuous rating, but in view of the widely different classes and requirements of electric service, and the indiscriminate use of ventilated and unventilated motors, little use could at present be made of this.

which are still operating on the Central London Railway. These machines had hollow shafts admitting air at the commutator end. The shafts were drilled radially, permitting the air to circulate through longitudinal and radial ducts in the armature core. No definite arrangement for the egress of the air seems to have been provided, however. In more recent designs radial ducts in the core have been quite abandoned in favour of longitudinal passages. The air is admitted, usually at the gear end, transmitted between the poles and over the armature surface to the commutator end, where it flows back through the commutator spider and along the core ducts to the fan, which is fitted at the gear end of the armature core and immediately next the air outlet in the casing. This is known as the series-fan system of ventilation; more recently, multiple fans have been introduced by which the air is all drawn in at one end of the carcass through all the passages in parallel and expelled at the other end. Thus there is no reversal of the air current, its volume and velocity are greater, and there

is no risk of sucking in the hot air just expelled from the motor, as is the case with the series fan where the outlet and inlet are necessarily close together. The increased velocity reduces to a minimum the risk of depositing dust or brake-shoe grindings.

In all ventilated motors properly so-called, the air circulation is effected by an exhaust fan of very compact type,

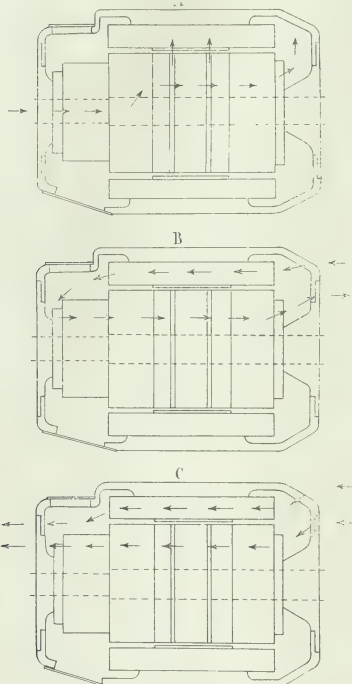


FIG. 11.—Systems of motor ventilation :

(A) GE for Semi-ventilation.  
(B) Series fan.  
(C) Multiple fan.

usually of aluminium or pressed steel, which is bolted to the armature core and actually forms the end core-plate. The velocity imparted to the air is sufficient to retain in suspension any dust which might enter the casing and to carry it out again. The drawback to the earlier semi-ventilated motor was that no positive velocity was given to the air, and also that the structure of the machines provided

dead-ends and pockets into which the dust, grit, iron oxide, and other particles were driven and permitted to accumulate. The present type of motor with its strong induced draught and clean-cut and direct air passages overcomes these drawbacks entirely.

Fig. 11 shows skeleton diagrams of (A) the old GE 66 system of semi-ventilation, (B) the series-fan, and (C) the multiple-fan methods of ventilation. Either of the latter is subject to modification where desired, as the inlets or both inlets and outlets can be closed where conditions require, and the motor will still run cooler than if no fan were installed, on account of the better interior air circulation.

Mention might here be made of forced ventilation by means of blowers. This expedient does not seem to be justified except where it is required to force the output of a motor beyond that obtained by internal ventilation. The device is at present almost wholly confined to locomotives where the equipment is under closer inspection during operation, and it is extremely doubtful whether it would attain any measure of success if generally applied to car motors.

#### HIGH-VOLTAGE MOTORS.

The increase in rated voltage to values higher than 600 followed immediately upon the introduction of commutator

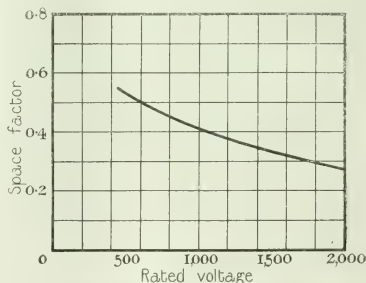


FIG. 12.—Space factors for railway motor armature-slots, mica insulated.

ing poles into railway-motor design; commutation was thereby so much improved that an increase of 100 per cent in the average volts per commutator segment was found permissible. Previous to this, however, it was a common commercial test to run non-commutating-pole motors on the test bed at 50 per cent and in some cases at 100 per cent overvoltage; with the later designs this was accomplished with a marked absence from flash-over tendencies.

The practicability of increased pressures of 1,200 or 2,400 volts has greatly broadened the limits of continuous-current working. Where these high pressures are employed it is generally for fairly heavy service of the interurban or extra-suburban order demanding powerful motors; this is a favourable feature, as in common with

other classes of electrical machines the high-voltage traction motor becomes a more economical proposition with increasing outputs. As will be surmised, there is a perfectly definite limit to the pressure which can be applied to the motor terminals, and this would appear to be about 2,000 volts for car motors of the type under review.

In any 4-pole series motor with a 2-circuit armature, the internal voltage at rated load is given by

$$V = 0.02 N \Phi /$$

where  $N$  = total number of turns on armature,

$\Phi$  = polar flux in megalines,

= frequency = r.p.m./30.

In another direction some latitude is permissible; with increased voltage of course the current to be commutated is reduced, consequently the commutator can be shortened in almost the same proportion. This applies to the working length and assumes a fixed brush width, though there may be cases where with a very high voltage the circulating currents between the toe and heel of the brush would necessitate a narrower brush. It is, however, generally found that the working length of commutator for 1,200 volts need be only half that required for 600 volts. Every inch by which the commutator is reduced may be added to the core length, thus immediately securing an increase in the effective flux passing through the armature. This very nearly compensates for the reduced armature loading

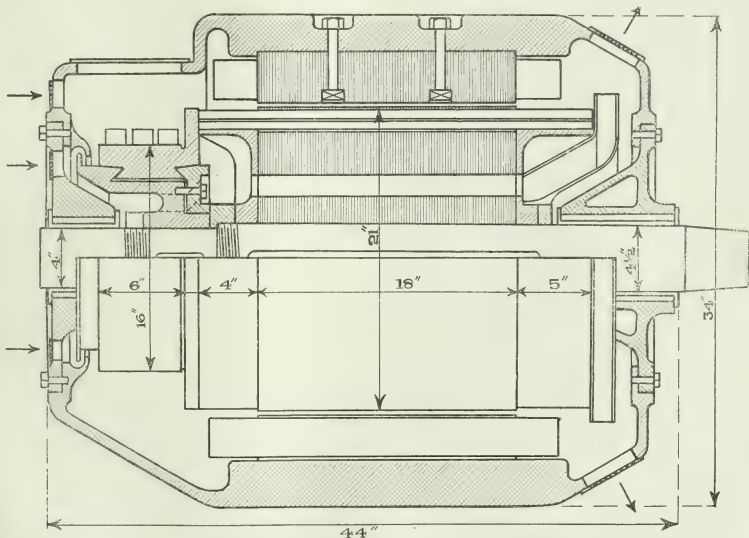


FIG. 13.—Section of 200-kw. 1,200-volt ventilated motor for field control.

Evidently in a motor of given dimensions  $\Phi$  is limited, and therefore an increased voltage can only be secured by a higher speed or a higher value of the armature loading. Higher rated speeds are being put out of court by the general adoption of field control, apart from the desirability of keeping the commutating constants as good as possible; hence to increase the number of turns in proportion to the higher pressure is the only alternative. The diminishing space factor of the armature slots, however, prevents this being effected in an armature of given diameter (see Fig. 12).

consequent upon the low space factor in the slots, and leads to the interesting conclusion that with given dimensions the higher-voltage motor needs to be designed for a stronger field and weaker armature. This is just the tendency required for a satisfactory design.

Table 4 on page 460 outlines the preliminary design features for three railway motors of 200-kw. rated output at 600, 1,200, and 1,800 volts respectively. The output has been taken as typical of that most commonly in demand for the railway-electrification work now in progress. For the reasons given on page 451 the most

powerful motor which can be economically used is the most satisfactory. At higher voltages this is still more true on account of the improved slot space factor accruing from the use of large strap conductors, wide rectangular slots, and the general cheapening of the design.

The two limits governing commutator design in high-pressure motors are the maximum permissible voltage per segment and the minimum segment width. It is evident that with one turn per segment, if the number of armature turns be increased, either the commutator diameter must also be raised or the bar narrowed down. Little latitude is available for the increase of dimensions, and the minimum allowable width of bar including mica is about 0.16 in., so that a definite limit is fixed in this direction. The limiting desirable average voltage per segment is believed to be 20 for a reasonably good field distribution. High-voltage design calls for low commutator speeds; and even though interpoles are fitted it is necessary to keep the commutating constants as conservative as possible.

If all these conditions are complied with, the design and manufacture of a satisfactory 1,200-volt motor is a simple matter, and that of an 1,800-volt machine, whilst being a slightly more heavy and costly proposition, is very little more so. Higher pressures than this do not seem necessary in view of the practicability of connecting groups of two or four motors permanently in series.

The three designs tabulated herewith are worked out for the same carcass and the same armature boring. The pole-seating in the 600-volt carcass permits of the extra punchings being added for the longer-cored high-voltage machines. According to the rated speed a field frame is generally employed for at least three different outputs of machine at the same pressure, so that if the same casing can be used for three different pressures, at least nine different forms of motor can be constructed from the same patterns. As will be seen, this gives reasonably good designs for the 600- and 1,200-volt motors, but owing to the high magnetic densities reached in the 1,800-volt machine it would seem to be improved by reducing the rating about 10 or 15 per cent. It is, however, sufficiently worthy of note that the same motor carcass which will give 200 kw. at 600 volts will also yield 180 kw. at three times this potential. Fig. 13 shows a longitudinal section of the 1,200-volt motor.

TABLE 4.

*Design data for 200-kw. railway motors, fully ventilated, field-control type. Continuous capacity 100 kw. with 60-degree C. temperature rise.*

**Electrical data.**

Rated voltage ...	600	1,200	1,800
Efficiency ...	88	88	87
Current, amperes ...	380	190	128
" per circuit ...	190	95	64
Speed, full field ...	450	450	450
" short field ...	550	550	550
Frequency ...	15	15	15
Product, turns X pole-flux ...	1,900	3,800	5,700
Turns on armature ...	180	288	360
Pole flux, megalines ...	10.6	13.7	15.9

Armature ampere-turns	34,300	26,800	23,000
per in. ...	520	405	350

**Armature.**

Diameter, in. ...	21	21	21
Gross core-length, in. ...	14	18	19.75
Net ...	12.6	16.2	17.6
D <sup>2</sup> L ...	5,600	7,140	8,600
Pole-arc, in. ...	10.7	10.7	11.6
Pole-pitch, in. ...	16.5	16.5	16.5
Total conductors ...	360	576	760
" slots ...	36	36	38
Conductors per slot ...	10	16	20
Current density, amps. per sq. in. ...	2,500	2,500	2,500
Size of conductor, in. ...	0.076	0.038	0.0256
Dimensions, in. ...	0.76 X 0.10	0.76 X 0.05	0.30 X 0.084
Slot space-factor ...	0.50	0.38	0.30
Dimensions of slot, in. ...	1.6 X 0.87	1.6 X 0.87	2.0 X 0.85
Slot pitch, in. ...	1.83	1.83	1.74

**Magnetic data.**

Flux density, armature core, kilolines ...	84	84	90
Flux density, teeth ...	148	141	149
" air-gap ...	65	65	69
" pole core ...	108	108	106
" frame ...	73	95	110
Ampere-turns, armature core ...	175	175	210
Ampere-turns, teeth ...	4,410	3,120	5,400
" air-gap ...	5,100	5,100	5,400
" pole core ...	315	315	280
" frame ...	350	980	2,240
" total ...	10,350	9,690	13,530

**Resistances.**

Length of armature turn, in. ...	67	75	78
Turns per circuit ...	89	144	180
Section of wire, sq. in. ...	0.075	0.038	0.0256
Resistance per circuit ...	0.0634	0.228	0.440
between brushes ...	0.0317	0.114	0.220
Armature current ...	380	190	128
Voltage-drop in armature ...	12.0	21.6	28.2
Voltage-drop in brushes ...	2.5	2.5	2.5
Armature I <sup>2</sup> R loss, kw. ...	5.50	4.60	3.94
Main pole, length of turn, in. ...	60	68	72
Main pole, no. of turns ...	28	51	105
" section of wire, sq. in. ...	0.25	0.125	0.070
Main pole, resistance ...	0.0054	0.022	0.086
Interpole, length of turn, in. ...	32	40	44
Interpole, no. of turns ...	29	58	87
" section of wire, sq. in. ...	0.25	0.125	0.0625
Interpole, resistance ...	0.003	0.015	0.049
Total field resistance ...	0.034	0.148	0.540
Field current ...	380	190	128

Drop in volts ... ..	13.0	28.2	69.0
Field I <sup>2</sup> R loss, kw. ....	4.95	5.35	8.85
Total I <sup>2</sup> R losses at rated load, kw. ....	10.45	9.95	12.79
Total I <sup>2</sup> R losses, per cent ... ..	4.60	4.36	5.60

*Commutator.*

Working length, in. ...	11.0	5.5	3.7
Total length, in. ....	11.5	6.0	4.2
Diameter, in. ....	16.0	16.0	16.0
No. of segments ....	180	288	360
Width of segment (inc. mica), in. ....	0.28	0.175	0.14
Volts per segment, average ... ..	13.3	16.6	20.0
No. of brushes per stud	4	3	2
Size of brush, in. ....	$2\frac{1}{4} \times \frac{5}{8}$	$1\frac{1}{8} \times \frac{5}{8}$	$1\frac{1}{8} \times \frac{5}{8}$

This paper is not intended to be a complete treatise on railway motors, but merely to summarize a few of the improvements which have been effected in this class of machine during the last few years and the main features of its present design. There is room for much more to be written on the subject, particularly on the behaviour of high-voltage motors in actual service.

The author's thanks are due to the Canadian Westinghouse Company and the British Westinghouse Company for some of the information contained in this paper, and to Mr. W. G. Gordon of the Canadian General Electric Company for many useful suggestions.

## DISCUSSION BEFORE THE INSTITUTION, 9 MARCH, 1916.

Mr. F. W. CARTER: I think this paper is very opportune, for it deals with an important and special subject of which the literature is considerably behind development. The author is wise in limiting the scope of the paper to continuous-current motors for multiple-unit trains, since the motors employed in locomotive work and in other systems of operation have many special features, and a technical discussion of the whole would form too large a subject for satisfactory treatment in one paper. The author appears to attach undue importance to the hourly rating of a motor; he expresses many of the results in terms of such rating; for instance, Figs. 1, 2, 3, 4, 5, and 8 are so expressed, whilst in Table 3 on page 457 he compares a number of motors practically on the basis of their 1-hour ratings. Now whilst this rating provides perhaps the most convenient method of expressing the power of a railway motor, it is not in any sense a criterion of the service capacity of the motor, and comparisons based on it are frequently fallacious. The meaning of the 1-hour rating is given in the Appendix on page 461, being taken from the American Institute's Standardization Rules. I was on the Committee that framed these Rules, and I may say that there was some discussion as to whether the 1-hour rating should be retained at all. It is not that there is particular objection to it, but that engineers generally attach too much importance to it; the 1-hour rating is apt to be regarded as a sort of criterion of the performance of a motor, whereas this is quite a misleading

## APPENDIX.

## EXTRACT FROM THE STANDARDIZATION RULES OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

*Railway Motors, Rating.*

*Nominal rating.*—The nominal rating of a railway motor shall be the mechanical output at the car or locomotive axle measured in kilowatts which causes a rise of temperature above the surrounding air by thermometer not exceeding 90 degrees C. at the commutator and 75 degrees C. at any other normally accessible part after one hour's continuous run at its rated voltage (and frequency in the case of an alternating-current motor) on a stand with the motor covers arranged to secure maximum ventilation without external blower. The rise in temperature as measured by resistance shall not exceed 100 degrees C.

The statement of the nominal rating shall also include the corresponding voltage and armature speed.

*Continuous rating.*—The continuous ratings of a railway motor shall be the inputs in amperes at which it may be operated continuously at  $\frac{1}{2}$ ,  $\frac{2}{3}$ , and full voltages respectively, without exceeding the specified temperature rises, when operated on stand test with motor covers and cooling system, if any, arranged as in service. Inasmuch as the same motor may be operated under different conditions as regards ventilation it will be necessary in each case to define the system of ventilation which is used. In case motors are cooled by external blowers the flow of air on which the rating is based shall be given.

view. It is not even true, as stated on page 457, that the 1-hour rating represents the maximum desirable current input for acceleration; for old types of tramway motors this was probably nearly correct, but I should say that as development proceeded the thermal rating increased at first faster than the commutating capacity. The result is that a motor like the GE 60, given in Table 3 as a 240-h.p. motor, was rated commercially at 200 h.p.,—240 h.p. the strict thermal rating, being considered to be too high a figure to furnish the normal accelerating current. Since then other tendencies have had effect, the commutating pole has been introduced with improved methods of ventilation, and the latest motors frequently accelerate at very much higher than their rated capacity. For instance, the GE 248, which is described in Table 3 as a 160-h.p. motor, would really accelerate quite as fast as the GE 60, which is termed a 240-h.p. motor. I wish to refer particularly to these two motors, in order to show that the 1-hour rating is not a fair criterion of the service capacity of a railway motor. The two motors are very similar, except that one—the GE 60—is of an old type. It will be noticed that they are of equal weight, and I may say that they have practically equal bodies, not in the sense that the frames are interchangeable, but that they would go on trucks having the same wheel-base and the same wheel diameter. They have equal armature diameters, namely  $18\frac{1}{2}$  in., and are used in America on wheels of 33-in. diameter. The GE 60 was designed for the Interborough Rapid Transit

Mr. Carter. Company which operates the subways in New York; whilst the GE 248 was designed for the New York Municipal Railway, which also operates in the subways of New York on a very similar service; to give an idea of the service I may say that it is much the same as that of our Underground Electric Railways of London. In this country railway engineers would not generally tolerate the small clearance, viz.  $3\frac{1}{2}$  in. above rail-level, that there is beneath these motors when carried on 33-in. wheels; the smallest wheels employed here with these motors are, I believe, 36 in. in diameter, used on the Underground Electric Railways, London; this gives 5-in. clearance above the rail-level, or  $3\frac{1}{2}$  in. above the fourth rail. On the Metropolitan Railway the same motor is used with a 38-in. wheel, giving 6-in. clearance. As a side issue I may say that on page 451, where the author refers to the size of wheel, he seems to imply that an armature of 20-in. diameter could be used with a 33-in. wheel; I am afraid we should require a 42-in. wheel at least for such an armature; the armature diameter of  $18\frac{1}{2}$  in. is about as large as could be used with a wheel diameter of 33 in., and the clearance underneath would then be only  $3\frac{1}{2}$  in. Continuing the comparison of the two motors, I have mentioned the features in which they are alike; they are alike in weight, in carcase, and in armature diameter. Then as to the differences, the GE 69 has a core length of  $14\frac{1}{2}$  in., whereas the GE 248 has a core length of  $11\frac{3}{4}$  in., the reduction being largely necessitated by the introduction of the fan. The GE 69 is one of the old type of motors without commutating poles and having radial ventilating ducts in the armature; the GE 248 has commutating poles and what is termed multiple fan ventilation, which is similar to that shown in Fig. 11 C, except in this respect, that the circulation of air is in the opposite direction, the air entering at the commutator end and leaving at the pinion end. Moreover, the GE 248 is a field-control motor, as the author mentions in the note below Table 3, although I do not know where he has obtained the figure of 25 per cent, for it should be more like 70 per cent. If now we look at the ratings given in the paper, it would seem that the design of railway motors has taken a retrograde step, for whereas in the GE 69, which was designed in 1902, the weight per kilowatt was 33 lb., in the GE 248, which is quite a recent type, it is 50 lb. Actually, however, a great advance has taken place of late years, but it is in service capacity and desirable operating features and partly at the expense of the hourly rating. That is the point I wish to bring out, viz. that the capacity for service of the GE 248 is greater than that of the GE 69, whereas the table would give the impression that it is very much less—about two-thirds of the amount in fact. The ventilated types of motor were introduced about 1911 by the General Electric Company of America. In these the outside air is carried through the motor quite freely, and at first there was a feeling that the motors would pick up dust, rain, and snow; they were in fact regarded with suspicion by operators and ridiculed by competitors. However, they are now almost universal for new installations in the States, and between 15,000 and 20,000 motors of the ventilated type, representing more than  $1\frac{1}{2}$  million horsepower have been sold by the General Electric Company alone, other manufacturers of course also making them. The author refers on page 457 to the GE 66 motor as a

semi-ventilated type operating on the Central London Metropolitan Railway, and he gives in Fig. 11 A a diagram of the supposed system of ventilation. I think, however, that there is a misconception in the matter; the motor was originally designed for the Manhattan Railway about the year 1900; one or two motors were made in the manner indicated, i.e. the shaft was hollow to the middle, and radial holes were drilled opposite to the ducts so that air could be drawn in from the outside and blown out through the radial ducts. The system was, however, confined to one or two experimental motors as it was found to produce very little reduction in the heating, whilst having the effect of collecting brake dust and depositing it in pockets in the motors; it was therefore immediately discarded and GE 66 motor as used has a solid shaft like the GE 69. I think the mistake arose through a longitudinal section of the GE 66 motor, showing the hollow-shaft feature, having been published in the descriptions of the Central London Railway and generally copied in textbooks; the motors on the Central London Railway have solid shafts like the motors on the District Railway. I wish now to make a reference to Fig. 13 and the typical motor design which the author presents. The first point I noticed about the design was that the bearings were unduly small, and this is a most undesirable feature from the operator's point of view. It is possible that the figure is not intended to be to scale, but I make out that the bearings of the motor armature are about 8 in.  $\times$   $4\frac{1}{2}$  in. at the pinion end and 5 in.  $\times$  4 in. at the commutator end. The GE 69 or the GE 248 which are motors rated at much less than 200 kw. (the supposed rating of the author's motor) have bearings of about 10 in.  $\times$   $4\frac{1}{2}$  in. at the pinion end and  $7\frac{1}{2}$  in.  $\times$   $3\frac{3}{4}$  in. at the commutator end; the bearings of the new Lancashire and Yorkshire Railway motor which has recently been described in the technical Press, seem to be about 12 in.  $\times$   $4\frac{1}{2}$  in. at the pinion end and  $10\frac{1}{2}$  in.  $\times$   $3\frac{1}{2}$  in. at the commutator end; whilst the W 339, which is the London and South-Western Railway motor has, I believe, 10 in.  $\times$   $5\frac{1}{2}$  in. bearings at the pinion end and  $7\frac{1}{2}$  in.  $\times$   $4\frac{1}{2}$  in. bearings at the commutator end. Altogether I think we should require at least 5 in. greater length in the bearings to make the author's into a satisfactory motor for this power, and we could hardly get this in without reducing the length of the core; it would indeed be inviting trouble to employ in a motor of this capacity such small bearings as he shows. The author again shows the lip of the commutator shell used as an oil thrower although it is a 1,200-volt motor. Those who have had experience with tramway motors know that one does all that is possible to prevent oil getting to the commutator shell, because it will ultimately creep round the lip and get between the laminae of the mica with the result that in the course of a few months an earth develops at the end of the commutator. On this account I think it is very undesirable to make use of the commutator-shell lip as the oil thrower, although it would seem that the new Lancashire and Yorkshire Railway motor uses this to form a secondary oil thrower, additional to the main oil throwers that are inside the cone of the commutator shell. A properly designed oil thrower would accordingly be required to make a satisfactory motor, and this again involves reducing the length of the armature core. Without going further it will be clear that we could not get anything like an 18-in. core

length on a standard-gauge motor using the forms of construction indicated. A somewhat longer core might be used with roller bearings, but with regard to these I should say that we have not yet had sufficient experience to be able to state that they would be satisfactory. A 200-kw. motor would also require a rather broad gear face—some engineers would in fact call for a 6-in. gear face, although I think them badly advised to do so—and that again cuts into the length of the core. I very much doubt myself whether we could make a 200-kw. motor of the ventilated type and of the armature diameter indicated by the author which could be got on an ordinary standard-gauge bogie; the designer is up against physical limitations, and there is no way of getting over them unless he is allowed wheels of larger diameter, or unless he can use roller bearings or something of that sort. The ventilated type, as may be inferred from the comparison I have given of the GE 248 and GE 69 motors, has usually a smaller 1-hour rating than the older types, and whilst we might get a 200-kw. motor of the totally enclosed type—in fact that is done in the case of the London and South-Western Railway motor, which, however, gives one the impression of being unduly cramped—I do not believe we should be able to get in one of the ventilated type, even with the reduced commutator length resulting from the use of a pressure of 1,200 volts. Finally, if I may make a suggestion to engineers who are calling for railway motors, it is this: in a matter in which physical limitations are imposed upon the designer it is very undesirable that he should also have artificial limitations imposed upon him, for they can rarely be met save at the expense either of service capacity or of operating merit. The limitations imposed by the service are all that are of consequence, and other restrictions almost inevitably react on the desirable features. Thus it is not wise to ask for a motor of given rating, for the rating is of no consequence; similarly it is unwise now to call for a totally enclosed motor. There is in some quarters a feeling that specifying a totally enclosed motor is equivalent to keeping a little in hand. The engineer thinks that if he calls for such a motor, he can at any time put grid covers on and thereby increase its capacity; actually, however, he is more likely to be spoiling the motor, he is probably cutting into the bearings and letting himself in for operating troubles in order to get the totally enclosed capacity; and when he fits grid covers he does not obtain so satisfactory an open-type motor as if the machine had been designed of a properly ventilated type.

Dr. S. P. SMITH: I have been very interested in the author's advocacy of field control, or rather his statement that field control seems to be becoming more popular. Field control is of course by no means new; it was in vogue before series-parallel control was introduced. Whilst that method was being developed, field control had to take a second place, but now that it has been found we cannot do as much as we should like with series-parallel control; we have to make use of both methods. The following consideration shows the great advantage of field control. From the equation for the electromotive force induced in a continuous-current machine  $E = n \Phi / k$ , where  $\Phi$  is the flux, and  $k$  is a constant for any given machine, we have for the speed  $n = k E / \Phi = k(V - RI) / \Phi$ . Varying the applied pressure  $V$ , as in the series-parallel connection, we

get voltage control, which is economical, but very limited in its range. Varying the resistance  $R$  gives resistance control, which is uneconomical because the pressure is lost in resistance. Nevertheless, at starting, resistance control is necessary to keep the current within permissible limits until the back electromotive force reaches a sufficient value. For a large back electromotive force we need a strong flux, which, however, must be weakened to bring the motor up to full speed. Thus, by adopting field control we can greatly reduce the starting loss by not using resistance solely to keep the current down. The flux can be varied by diverting part of the current from the field winding. The loss in a diverter is very small indeed, and is outside the motor. We can also re-arrange or disconnect part of the field coils to reduce the flux. For instance, if we have four coils (N, S, N, S) normally connected in series, we can take them in pairs and connect them in parallel. Owing to the great advantage of field control, it is very satisfactory to learn that present practice is moving in that direction. Unfortunately it is not easy to apply field control to systems that are already working. If we consider the District Railway or the Metropolitan Railway or any of our important electric railways, where interchangeability is all important, the number of types of motors used must be reduced to the absolute minimum, because every type of motor has to have its own stock parts. Therefore, whilst it may cause a large saving in current consumption to introduce field control, it is necessary to remember that the cost of alterations would be enormous in many cases, and would make the adoption of that system impossible. Another point that must be taken into account is that the design of the motor for series-parallel control alone is not the best for field control, although my calculations for one of the latest GE motors show that field control would give very good results by using such a connection as I have described. Then I should like to refer to the author's designs. Following on what he states has been done, I cannot agree with all he says in regard to what might be done. Turning to the section dealing with high-voltage motors, on page 460 the author gives comparative designs for a 200-kw. railway motor for three different voltages. The 600-volt motor is on fairly standard lines, and I shall say nothing about the 1,200-volt motor, because the 1,800-volt motor particularly brings out the point to which I wish to refer. On page 461, it will be seen that for the 600-volt motor the average volts per segment are 13.3. That agrees very well with the figures given in the table of standard motors, and also with what is done with rotary converters. An average voltage of 13.3 may mean a maximum of about 20 volts, which is about as high as a designer cares to adopt normally. For the 1,800-volt motor, however, the average voltage per segment is 20; whilst the author says on the preceding page: "The limiting desirable average voltage per segment is believed to be 20 for a reasonably good field distribution." That is what I want to get more information about. I should like to know whether that is really safe, because a mean voltage of 20 can scarcely have a maximum of less than 30 volts per segment, and when a spark starts with 30 volts it can be maintained. For traction motors, service conditions are usually worse than test conditions in this respect; thus when a motor has been out on the road doing fairly rough work, carbon

Dr. Smith.

Dr. Smith. dust gets in between the segments, and it is not very difficult for sparking to be started, even with interpoles. Even if there is not much sparking under the brushes, to have 30 or more volts per segment is rather risky. Comparing this with rotary converters, I once heard Professor Walker say he had often observed rotary converters working in the dark, and under the pole where the maximum voltage per segment was he could see a continuous stream of sparks, but in the polar gap it was quite dark, *i.e.* the commutation was quite good, but some sparking was going on due to the carbon dust, etc., in the grooves. Such a state of affairs is undesirable, although of course it may be safe if the working conditions are steady, but with a traction motor where the current may vary very rapidly and even be interrupted, and where there is intense vibration, I do not think we can use a mean pressure of 20 volts per segment without considerable risk. I am anxious to hear whether such voltages have been used, and, if so, what precautions are taken to prevent flashing-over. It is scarcely possible to use more segments, for, as it is, the segment pitch is only about  $3\frac{1}{2}$  mm., or  $0.14$  in., which is very small. It will be noticed that in order to get the winding in at all the author has to use 20 conductors per slot, that is, 10 segments per slot. That may be satisfactory for traction work, but I should not care to use 10 segments per slot in either a generator or a rotary converter. I should like to hear the author's view as to whether those figures are really practicable, or whether he is not really trying to do too much and forcing the motor into too small a space for that high voltage. I myself think he ought to have a larger diameter, *i.e.* a larger motor.

Mr. F. LYDALL: The first point I wish to refer to is with regard to field control, not so much to its theoretical advantages as to the way in which it is most conveniently carried out. Dr. Smith has sketched on the board a method for a considerable degree of field weakening, namely, by taking two north poles and paralleling them with two south poles. There are a good many ways of cutting down the field strength, and the method he has shown is perhaps the most expensive from the point of view of the number of connections inside the motor. Inside a railway motor, and a tramway motor too for that matter, there is exceedingly little room for additional field connections, and it is most desirable that they should be cut down to the minimum. As a matter of fact, the first method adopted for carrying out the field shunting was by diverting a good deal of the current from the field coils by a diverting resistance, and that undoubtedly is the most convenient method, simply because we do not add at all to the number of leads coming out of the motor or to the internal connections between the field coils. As is mentioned in the paper, however, this leads to trouble, because after a momentary interruption of the voltage the current has two paths along which to flow in its way to the armature; it can go either into the field windings, which are inductive, or through the resistance, which is non-inductive, and then on to the armature. Naturally, as it is a question of time, the current passes principally through the non-inductive resistance and not through the field coils, and therefore the back electromotive force of the motor is small. It is this which has caused a great deal of trouble from time to time in flashing-over, namely, that

an excessive current passes into the motor at the moment Mr. 1 when the interruption ceases and current is restored, and the commutating pole has not time or strength to deal with it. There are ways of getting over this difficulty, one of which has been suggested and has been tried in various places, namely, that a relay of some kind should be used so that if there is any interruption of the voltage at the time when the fields are weakened, the field weakening connections should be completely cut off the moment the current is interrupted, and should not be restored again either until the motorman moves the controller back to the control notch corresponding to full field and then again on to the full-speed notch, or after some definite time as determined by a time relay. This is not necessarily a very successful method of avoiding trouble. It requires a particularly sensitive relay, and anything like a sensitive relay in traction work should be avoided. Then we come to the alternative suggestion, namely, cutting out part of the field winding. There are various ways of doing that. We can cut out perhaps the two bottom poles; but if we do so there is some possibility of there being a considerable upward pull on the armature, which would interfere with the satisfactory working of the bearings. If we cut out alternate poles, say two north poles, we are liable to interfere with the proper distribution of the commutating flux in the interpoles, and if we do that there is a possibility of sparking just when we do not want it. Then there is the method mentioned in the paper, namely, tapping off near the middle point of the field windings. That is a very vague phrase. The only satisfactory way to do it is to divide each of the main coils into two parts, connect them all up in a complete series, and cut out half of each by taking out a connection from the middle point of the series. That means quite a number of internal connections, which are most undesirable; but in the result we do get only three leads coming out from the field windings. That is presumably what the author means when he speaks about the standard method of taking a tap from the middle of the coils, and perhaps that is the best thing to do. If some method could be devised whereby the standard arrangement of coils could be obtained and we could avoid the troubles introduced by simply diverting current through a non-inductive resistance, it would be very much better. The only other point I will mention is the maximum value of the average voltage to which Dr. Smith has referred. I think it is most undesirable, in considering the properties of a high-voltage motor, to say much about the average voltage between commutator segments. As a matter of fact the average voltage means nothing. It does not represent any definite physical fact; it is purely a numerical quantity. The factor which has to be considered is the maximum voltage, as Dr. Smith said. To show how these quantities vary in different conditions, I may instance a case in which I designed a motor for operation with field control. The average volts per segment were something under 18, but under the worst running conditions, for which I was particularly anxious to design the motor, the maximum volts per segment were something over 45. Although 18 is a fairly high figure, it is not unreasonably high, but I certainly think one must draw the line at some value for maximum voltage below 45. Naturally we get worse con-

ditions when we have field control due to increased distortion. I notice in that respect that the 1,800-volt motor which the author has designed is intended not only for the full voltage but also for field control. I think we must be especially careful, in designing a motor for field control, to consider how the weakening of the field will affect the value of the voltage between segments, *i.e.* to consider how far we can go in shunting the field without arriving at the condition in which any slight sparking will cause a flash-over. The various details contained in Table 4 are certainly rather surprising in some respects. The number of misprints appears to be considerable. In the 1,800-volt motor the number of slots is given as 38. I think it should be 36, as that corresponds with the number of commutator segments. The slot pitch is given as 1.74. I think 1.83 should be the figure, the same as in the 600-volt and 1,200-volt motors. The number of conductors per slot is given as 20, which produces a winding not impossible but certainly very difficult. Finally, there seems to be a curious idea about the number of commutator segments for a 2-circuit series winding. I notice that all these motors have an even number of commutator segments. If I am not mistaken, that means that there must be one dead segment, which is not good practice; and the same feature occurs in the standard motors given in Tables 1 and 2. Finally, the number of slots seems to be very small and this leads to a very wide slot. Although that may be good practice for a non-interpole machine, it is not for an interpole motor, because it requires a wide interpole face and an unnecessarily large interpole.

Mr. E. G. BARTON: It is stated in the paper that much trouble arises owing to the use of a diverter which is devoid of self-induction. I wonder whether inductance has ever been used in the diverter circuit. It seems to be almost an obvious remedy, but probably there is a strong reason against it.

Mr. J. S. HIGHFIELD: I should like to refer briefly to the point raised by the last speaker. I am very glad he asked a question about the use of inductive shunts, because it occurred to me that probably they had been used for the purpose of controlling railway motor fields. In fact for the control of the fields of series generators a common method is to shunt the main field with a diverter, and I have several machines controlled in that way. Originally we used non-inductive shunts, and we had trouble from the cause clearly explained by Mr. Lydall; the variations in current took place through the diverter instead of through the field, where we mainly wanted them. We then altered the shunts by making them more inductive than the field, which was quite a simple change, so that the degree of regulation was at once rather increased than decreased, as had been the case before. The change from the non-inductive to the inductive shunt was entirely successful with these series-wound generators and motors and would be, I am sure, equally effective for railway-motor fields.

Mr. R. T. SMITH: I do not propose to reply to the discussion but to leave that to the author to do so. Meanwhile I may perhaps make a few remarks on the discussion. Mr. Carter said that too much importance had been attributed to the hourly rating of motors, with which the author agrees, emphasizing his reasons by Figs. 8 and 10, and his remarks thereon. The author strongly urges that traction motors should be specified and bought on their continuous

rating as well as on their hourly rating. It must never be forgotten that the hourly rating of any short-time motor is a pure convention, simply used for the convenience of having some basis on which motors can be compared, but that such a comparison must never be pushed too far. The Engineering Standards Committee has not yet legislated for traction motors in this country, although the American Institute of Electrical Engineers has done so, and for the time being we are glad to use the American standards. Mr. Carter also criticized Fig. 13, dealing with the author's design of a 1,200-volt motor. I think I may agree on behalf of the author that there are some defects in that design. Besides the small bearings and the oil thrower at the end of the commutator, there is no doubt that for a 1,200-volt motor there is too little clearance between the end of the commutator and the casing. Anybody who looks at the quite successful design of the 1,200-volt motor now in use on the Lancashire and Yorkshire Railway, between Manchester and Bury, will find that all such clearances are appreciably increased as compared with Fig. 13, but in spite of that they have designed a most successful type of 1,200-volt motor. Other criticisms with regard to the design, and especially as to the length of the armature core, I will leave the author to reply to. As a railway man I heartily endorse what Mr. Carter said about the impropriety of the railway imposing on the designer other limitations than those already imposed by the actual physical dimensions to which railway motors have to conform. The railway motor is purely a compromise between a great many conflicting requirements. All that can be said is that the less the designer is limited in any direction, beyond the limits imposed by the size of the bogie and the load gauge, and the more he is asked for a result within these limits, the better that result will generally be, provided that he knows his business. Dr. Smith discussed field control, and Mr. Lydall gave some very practical illustrations of its difficulties. As far as their remarks were criticisms of what the author says I do not attempt to reply to them, but I think it is worth while adding, from the railway point of view, that field control in a railway motor is one of the two things that if successfully developed may make the continuous-current series motor really useful for most railway purposes. The other feature, regenerative control, which is now being successfully used in the United States, is not mentioned in this paper. We shall probably hear more of it next week in Mr. Storer's paper. These two features appear to me to be of singular importance as making the continuous-current series motor more fit than it has been before for the various classes of work that the railway man demands of it. Both Dr. Smith and Mr. Lydall criticized Table 4 on page 460. Those criticisms I propose to leave entirely to the author. I am very glad that Mr. Barton raised the point about inductive shunts, giving Mr. Highfield the opportunity of telling us his experience with their use in the regulation of the Thury type of continuous-current machine. Where shunts are used for field control an inductive shunt may get over the difficulty mentioned by Mr. Lydall, and such shunts have been used for traction motors. When this paper was read in Manchester I made some remarks\* as a contribution to the discussion, and trust I have not encroached on them here.

\* See page 471

Mr. Dover.

Mr. A. DOVER (*communicated*): The author has presented a number of interesting points in connection with railway motors and shows in a very striking manner the rapid strides which have taken place since the introduction of commutating poles. On page 450 we are given comparative data of two motors, from which the author deduces that a certain commutating-pole, self-ventilated motor is 24 per cent lighter than a non-commutating-pole, non-ventilated motor of equal rating. An important item in the data—the rated speeds—is missing. Moreover, the rating given for the commutating-pole motor (GE 201) refers to 600 volts, while that given for the GE 74 motor refers to 500 volts. Under these circumstances we cannot regard the data as representing a true comparison, on account of the large difference between the speeds. For instance, the rated speed (at 600 volts) of the GE 201 motor is 720 r.p.m., which is nearly 30 per cent higher than that of the GE 74, 500-volt motor. With reference to the alternative motor equipments given on page 451, alternative II offers further advantages over I in the lower maintenance costs of the equipment and the lower energy consumption, the saving in the latter being due to the higher efficiency of the equipment and the lower rotational energy of the train. The author's remarks in connection with rheostats, contactors, etc., require modification, as the 4-motor equipment (of 90-kw. motors) could be controlled by the same series-parallel contactor-group and rheostats as the 2-motor equipment (of 180-kw. motors).<sup>\*</sup> The control equipments would then only differ in the reversers, the 4-motor equipment requiring a reverser, with cut-out switches, suitable for four motors. The author's remarks in connection with wheel diameters (page 451) are not representative of the conditions obtaining in this country, where wheels of 42–43 in. diameter are standard for surface lines and wheels of 36-in. diameter are adopted for tubes and underground lines.<sup>†</sup> In obtaining 20 in. as the maximum diameter of armature for use with 33-in. wheels, the author has apparently allowed insufficient clearance under the motor to obtain the full life from the wheel tyres. With a motor of the size considered in the paper, the radial thickness of the bottom pole-piece<sup>‡</sup> and frame is between 5 and 6 in., so that with an armature of 20-in. diameter there would be only about 1 in. to 2 in. clearance—between the bottom of the motor and the top of the track rails—with 33-in. wheels and new tyres. This size (20 in.) of armature requires wheels of at least 40-in. diameter. On the subject of rating, the author lays considerable stress on the 1-hour rating, which, however, is purely arbitrary and gives no indication of the service

capacity of the motor. This is particularly the case with a self-ventilated motor, for which the service capacity is considerably higher than that of a non-ventilated motor having the same 1-hour rating. The statement (on page 455) that the non-ventilated, the self-ventilated, and the forced ventilated motors are all brought into line on the 1-hour rating, is not in agreement with the American Institute's Standardization Rule (see Appendix, page 461). This rule prohibits external blowers. Hence the self-ventilated motor with its induced ventilation will have an advantage over the non-ventilated and forced-ventilated motors, but the full advantage of the self-ventilated motor is only obtained under service conditions. The forced-ventilated motor (ventilated by means of an external blower) possesses several advantages over the self-ventilated motor for locomotives, since a number of motors can be ventilated efficiently from one central blower. For motor-coaches the forced-ventilated motor is undesirable on account of the increased weight of the blowers, air ducts, etc., and the maintenance thereon. Attention may be directed to Tables 1, 2, and 4, which contain a number of misprints in connection with data relating to the armatures and commutators. For instance, the even numbers (148, 160, 234, 170, 168, 258, 186, 180, 288, 360) for the commutator segments cannot give symmetrical 2-circuit armature windings with a 4-pole machine, and no manufacturer of repute would introduce dissymmetry by the insertion of "dummy" segments. In the design data given in Table 4 the coils per slot and the average voltage per segment in the 1,200- and 1,800-volt motors are undesirably high, while the number of slots is decidedly low for commutating-pole machines. These features would undoubtedly lead to poor operation. It may be remarked that railway motors must withstand brief interruptions in the supply circuit and also sudden variations of voltage without flashing-over. These considerations prevent the use of values, for the average voltage per segment and armature ampere-turns, which might be tolerated in stationary motors. Presumably Fig. 13 is intended to be only diagrammatic of the principal magnetic and electrical dimensions, otherwise attention might be directed to mechanical details such as the frame heads and bearings. The former require to be of larger diameter in order to permit the removal of the armature (since a split-frame 200-kw. motor would not be used in practice); while the bearings are too small for satisfactory operation under service conditions. The ratings for both the 1,200- and 1,800-volt motors should be reduced, and the diameter of the commutators of these motors should be increased to permit of a larger number of commutator segments and armature turns, thereby allowing a lower flux per pole to be adopted. The number of slots should also be increased to give better commutating conditions.

(Mr. PANNELL's reply to the discussion will be published in a later issue.)

#### MANCHESTER LOCAL SECTION, 22 FEBRUARY, 1916.

Mr. Ferguson.

Mr. T. FERGUSON: I am convinced that the railway engineer should have sufficient knowledge and experience of motor design, and the designer sufficient knowledge of the application of the motor to railway service, to allow them to collaborate to good effect; and it is mostly on

those parts of the paper which deal with this aspect that I wish to comment. At the outset the author describes a typical urban heavy railway service and shows the desirability of minimum weight. This is a very important point and should be more appreciated by railway men

<sup>\*</sup> The four 90-kw. motors would be arranged in two pairs with the motors of each pair connected in parallel. This method has been largely adopted with motor equipments having motors of 100–120 kw.

<sup>†</sup> The use of standard 42–43 in. wheels is essential if electric stock is to be interchanged with that operating on other lines. In this connection see paper by Mr. H. W. Firth, *Journal I.E.E.* vol. 52, p. 1009, 1914.

<sup>‡</sup> The axes of the poles are assumed to be vertical and horizontal.

Mr. I. SOB.

than it seems to be. In countries where coal is expensive, as for instance in the Argentine, the yearly cost of carrying an extra ton of equipment on a city and suburban service may easily reach £10 per annum, which is certainly quite a consideration; and after the electrical equipment designer has strained every nerve to reduce the weight of this equipment as much as possible, he is sometimes disconcerted to find that the coach builders have increased the weight of their coach bodies and underframes in every coach to the extent of a ton or two more than the original estimate. If there is much yet to be learnt in the proper design of electrical equipments for minimum weight, I feel sure there is still more to be learnt in this direction in coach building. The adoption of a motor equipment consisting of two large motors rather than one consisting of four smaller motors has very much to recommend it. For an urban service as indicated on page 449 it is a matter for careful consideration whether it will not pay to adopt an acceleration nearer to 1 mile per hour per second than  $1\frac{1}{2}$  m.p.h. per second (which the author states is the least that will do) in order to use a 2-motor equipment. With the train weight which he gives, it would of course be impossible to run with an acceleration of  $1\frac{1}{2}$  m.p.h. per second with a 2-motor equipment having two motor-cars and three trailer cars. Of course, other things being equal, the higher acceleration would give a lower current consumption, but the schedule indicated in the paper is not only possible with 1 m.p.h. per second but is actually in operation on parts of the London Underground Railways system. The saving in cost and weight accruing from the use of the 2-motor equipment is great, but not quite so great as indicated by the author, because the continuous capacity of the 180-kw. motor would not be double that of the 90-kw. motor. With non-ventilated motors this is especially the case, as the radiating area of the motor frame does not increase in anything like proportion to its 1-hour capacity. Then as regards the difference in cost, it is not always necessary to duplicate the contactors, cables, etc., since a 4-motor equipment may be controlled on the so-called "simplex" system; that is, two motors may be permanently grouped together in parallel to operate as a single motor. This enables us to use the same number of contactors as for a 2-motor equipment. However, cables, conduits, and certain other items of the equipment are certainly more expensive, and there is no doubt whatever that a 2-motor equipment is cheaper in first cost and in maintenance and may easily result in a lower energy consumption per train-mile than the 4-motor equipment. When standardizing on a 2-motor equipment especially, it is generally considered good practice to adopt the largest motor that can be fitted on to standard wheels, having due regard to preserving sufficient clearance above the rail-level and the floor of the car, since, when traffic increases, the service conditions are always harder and considerable tendency is invariably found on the part of the traffic department to increase the schedule to the utmost limits of the motor capacity. In this connection the author urges the increase of the rating of the motors on their so-called continuous-service rating by means of fans fitted to the armature shaft, which could draw cool fresh air from the outside and pass it through the motor. However, he does not appear to favour forced ventilation by means of separate motor-driven blowers except on loco-

motives. For my own part I think that independently. Mr. Ferguson.  
driven blowers may be used with great advantage on motor coaches; as a matter of fact they are being used in a number of instances, and I believe that sooner or later we shall see notable extensions in this direction. The amount of air which can be passed by the fans on the armature shaft is comparatively limited, while the quantity that can be passed by a separate fan is enormously greater, and as a result the continuous capacity of the motor is greatly increased. The author's contention that fine grit or dust drawn into the motor is not permitted to settle there owing to the speed of the air draught, is true to an even greater extent when forced ventilation is adopted. Further, there is generally less difficulty in drawing the air from some place where it is more or less free from dirt and brake-shoe dust. The 2-motor equipment lends itself much better to a forced ventilation scheme than a 4-motor equipment, since the arrangement of the air ducts is simpler. The author discusses the use of high-speed and low-speed motors and points out that the efficiency of the high-speed motor is better at rated load and inferior at light loads when compared with the low-speed motor. He recommends a high-speed motor with large gear ratio for short runs and a low-speed machine with small gear ratio for operation on long straight-away runs with few stops. He further discusses the very important subject of the shape of the characteristic or speed curve of the saturated versus the non-saturated field motor, and states that for frequent-stopping service involving rapid acceleration the non-saturated field is preferable. This is quite true if the saturated-field motor is of the same speed as the non-saturated field motor because the latter machine will tend to maintain an acceleration after coming off the rheostats more than a saturated machine would, and thus permit coasting down to a lower speed. However, we cannot have the advantage of a non-saturated motor without paying for it, since a non-saturated motor of the same speed will be heavier than the saturated machine. For short runs, one generally finds that it is better to employ the material in making a low-speed motor in order to avoid rheostatic losses during the acceleration; but of course each case requires a very careful study of conditions. I am assuming, of course, that it is not possible to make a further increase in the gear ratio owing to clearance of the motor above rail-level and to minimum size of pinion. In short runs, although a high-speed motor with large gear ratio is the best, it is often impracticable to get the desired ratio owing to limitations as to the minimum size of the pinion and the maximum size of the gear-case for rail clearance. If prepared to sacrifice clearance and to take chances by using small pinions, much can be done to lower the energy consumption, and it is a matter for compromise and judgment. The author also touches on the subject of the field-controlled motor and points out its usefulness in operating a service with diverse characteristics, for example, a stopping suburban service and non-stop suburban service, with the maximum economy possible. Again one cannot have field-controlled motors without paying for it, as the author very clearly shows in the tabulated weights on page 454. In Fig. 7 he shows a typical characteristic for a field-controlled motor on which the ratio of full field to weak field appears to be about 2 to 1. However, I would point out that the speed curves could

Mr. FRITH not possibly have the relation to each other shown in that figure at light loads, since at 20 miles per hour the ratio would appear to be 3/8 to 1 instead of 2 to 1.

Mr. J. S. PECK: The designing of railway motors is a subject of growing importance and one which has not received the amount of attention by the Institution which it deserves. This paper is especially interesting, as it summarizes the general position of railway-motor design to-day and also indicates the direction in which designers are moving. In connection with the statement on page 449 that 1895 saw practically the end of the trial-and-error stage, it is interesting to note that in 1892 Mr. Lamme brought out a railway motor in which he had a closed waterproof motor, single-reduction gears, four field coils spaced at  $45^\circ$  to the vertical, a slotted drum armature, former-wound coils, and a 2-circuit winding. Thus in one step he advanced the whole construction of railway motors from a very chaotic state into one in which for many years only minor improvements were made. Not until the commutating pole was introduced was there any material change, and the essential features of Lamme's design are all embodied in the standard railway motor of to-day. The ventilated design with the double or parallel-flow air circuit represents the latest development and, as the author points out, it has enabled the motor to carry a much heavier continuous load than could be obtained before. It has not been introduced extensively into this country, but as our tramway systems increase and more railways are electrified it will certainly be adopted. Eight or ten years ago an attempt was made to run railway motors and tramway motors with the commutator cover removed, as it was thought that better cooling would be obtained, but there were difficulties owing to the amount of dirt which accumulated in the motor and eventually resulted in the breakdown of the insulation. The modern motor is of a very different construction, at least in so far as the insulation is concerned. The great trouble with the old motor was the fact that the armature coils where they projected beyond the core were unprotected, so that dust of all kinds lodged in the end winding and breakdowns occurred over the surface of the coils or where the coils left the slots. In the later designs the whole of the end winding was totally enclosed, usually with a canvas cover, so that no dust could get in and work round the coils. Also the ducts inside the armature have been eliminated or have been placed in such a position that they cannot possibly damage the insulation of the coils. In many armatures the insulation at the end of the slots has been reinforced, that is to say the slots in the last few laminations, for perhaps  $\frac{1}{2}$  in. or 1 in., are slightly larger than the rest of the slot. This enlarged space carries additional insulation which protects the coil at the weakest point just where it leaves the core. Moreover, the insulation has been greatly improved by using fire-proofing materials. A large modern motor is insulated practically throughout with mica and asbestos, so that although it may run at a high temperature, perhaps considerably in excess of  $100^\circ\text{C}$ ., there is no fear of the insulation burning out. Under the heading of "High-voltage Motors" the author refers to 1,200 and 1,800 volts on a single commutator, as though it were a very simple matter to build such a motor, but it has taken a very long time, even after the introduction of the commutating pole, to produce a motor which will operate

satisfactorily even at the lower voltage, and I think the majority of railway engineers to-day would have some hesitation in going to as high a voltage as 1,800 on a 4-pole motor of the ordinary construction.

Mr. J. FRITH: I want to couple the remarks in the paper to the effect that commutating poles make flashing-over less likely and that they increase the possibility of raising the speed by field control, with another remark about the maximum permissible voltage per segment on the commutator. These two things have a very direct connection. Commutating poles have taken away the "danger flag" of flashing-over, namely sparking, and just for the moment it may seem that they have also taken away the danger of the actual flash-over. There is, however, a constant temptation for the manufacturer to make use of the fact that commutating poles have taken away sparking, in order to increase the volts per commutator bar, and at the same time to take advantage of the possibility of speed regulation; in which case with the weakened field the full voltage is crowded on to perhaps half—or even less—of the bars between the brushes, and we may again be troubled with flashing-over. I am interested in the way the question of ventilation has been handled. To those of us who have been accustomed to putting industrial motors into dusty positions it seems that the advantage of the self-ventilating motor should have been grasped much sooner than it has been. One point in its favour in comparison with the separately ventilated motor is the greater ease with which the air currents can be divided; the fan at the end of the armature can be made to take the right proportion of air through the armature and past the field coils. I think, however, more could be done with the design of these fans. Although they are fairly efficient, I think designers have not sufficiently studied the laws of the type of paddle-bladed fan which is used with a motor that has to run in either direction. They do not seem to study the angle at which the air comes off the fan blades, and the effect of the depth and number of the blades.

Mr. W. C. SCHACHER: The author has introduced an important and welcome change by substituting the kilowatt for horse-power in the rating of motors, and I think it would be in the interests of all concerned if this innovation were to be adopted universally. In my opinion the 1-hour rating, which is now universally used, very urgently needs revision. The practice was adopted originally and was found serviceable when motors were built to be much heavier for a given output than they are now, and when ventilation as it is applied to-day was practically unknown. The designer then, when rating his machine, was entirely dependent on the amount of heat radiation he could obtain through the surface of the motor, and from the thermal constant he could more or less form an idea what the motor would be capable of doing under service conditions; in other words under continuous load. These conditions have entirely changed during the last few years, first by the introduction of the light-weight motor, and secondly by the increase of its capacity by means of the application of various forms of ventilation, so that in a modern motor there is not the slightest relation between the 1-hour rating and the possible continuous output. I doubt whether the designer of a modern motor can get much support in his calculations from the 1-hour rating, and unless he is required to put the figure into some purchaser's specifica-

tion I question very much whether most of them would ever trouble to ascertain it. Take, for instance, the case of a motor which was only recently built. Under the old conditions this motor would have a 1-hour rating of about 200 kw. at 75 degrees C. rise, and a continuous rating of 119 amperes at 360 volts, say 43 kw. at 45 degrees C. rise. Now this motor has been adopted for forced ventilation by fixing a fan on the motor shaft and by using an external blower by means of which the motor is supplied with air at the rate of about 400 cubic ft. per minute. Although the 1-hour rating of the motor is only slightly increased, the permissible continuous load is raised to something like 280 amperes at 300 volts, *i.e.* 84 kw. for the same temperature rise, or an increase of 95 per cent over the old type of motor. In computing the value of a modern motor from the capacity point of view, and this is really the determining factor, the continuous rating in kilowatts and say half or three-quarter voltage appear to be sufficient; whilst to judge it from the service point of view either its characteristic or at least 3 or 4 points on the curve are certainly required. In Fig. 3 I think the author has somewhat overestimated the kilowatt output for a given  $D^2 L$  at the higher ratings. The curve shown might pass through 6,600  $D^2 L$  at 220 kw. rated output. With reference to the diameter of the motor-coach wheels, considerable progress has been made in this direction lately and diameters have been considerably increased. Many railway companies are now adopting the standard 42-in. wheels, and some have even gone further and are using wheels of 43 in. or  $43\frac{1}{2}$  in. diameter. In Fig. 11 the author shows three distinctly different types of ventilation. The multiple fan or parallel system has undoubtedly great advantages over the other two systems, since with this method the cool air comes into contact with both the field and the armature, whilst in the series system the air has to pass through either the field or the armature first, with the result that in a normally designed motor one, depending on the flow of the air, will heat up considerably more than the other. In Fig. 11 C the author shows the flow of air in the direction from the pinion to the commutator, which I assume will necessitate a fan at the commutator end. This method of course has the advantage that the copper and carbon dust from the commutator is directly ejected into the air. It has, however, been found extremely difficult to mount the fan on the commutator end, and so far I am not acquainted with a construction which carries a fan in that position.

Mr. H. ALLCOCK: This paper should serve to accelerate the more general adoption of continuous-current electrification at pressures higher than 600 volts. Hitherto I have understood that the equipment on the train itself, *i.e.* the motors and their controlling apparatus, has been the stumbling block when the use of continuous current at 1,200 or 2,400 volts has been under consideration. The author now shows that the shorter commutator of the 1,200-volt motor, compared with that of the 600-volt motor, has a marked advantage, since the overall length of the armature is rigidly limited by the standard rail-gauge of 4 ft. 8½ in., which is hardly likely to be increased for the convenience of the electrical engineer. We might thus shortly arrive at a state of affairs when the motor designer will not only cease to oppose, but will actively support the adoption of higher working pressures on continuous-current traction systems. Having reached this stage the

development of high-tension continuous-current traction should proceed rapidly, since other writers have already established that substantial economies would follow the adoption of a higher voltage at the motor. I refer more particularly to the reduced cost of sub-station plant, and to the smaller currents to be catered for between the sub-stations and train motors.

Mr. W. A. BARNES: In the opening paragraphs of the paper it is stated that the average conditions for urban and suburban railway service are trains of 150 tons, running at a schedule speed of 16 m.p.h., with two stops per mile. This presumably applies more particularly to underground railways and others of like nature. Very different conditions obtain, however, on surface railways, especially in the case of the electrification of existing steam trains. The average distance between stops in this case can be taken at approximately one mile, and the schedule speed 25 to 30 miles per hour; and as a consequence of the heavy duty the weight of a 5-car train is increased to 200 tons. The 16-m.p.h. schedule is very little if any better than that of the steam train, and therefore no advantage is taken of the greatest characteristic of electrification, *i.e.* rapid acceleration and retardation and the consequent low ratio between maximum and average speed. This latter is necessary on a busy suburban line where stations are placed geographically, if the required headway is to be maintained between trains, and if the number of trains per hour is increased to meet traffic requirements. These conditions bear very seriously on the design of railway motors. It is not quite clear what is meant by average initial acceleration. If this is taken during the notching period it should, to meet the foregoing conditions, be of the order of 2 m.p.h. per second, with an aggregate tractive effort at the wheel treads of 32,000 lb. It is necessary to use four motors per motor car in order that the requisite adhesion may be obtained, and these motors will be of about 200 h.p. each. For heavy electric traction, therefore, no saving could be made by employing fewer motors at high capacity in the manner shown by the author on pages 450 and 451. Referring in passing to the author's assumption No. 3, page 449, it is news to learn that the term "horse-power" is obsolete, and whilst not quarrelling with the term "kilowatt," previous to this paper I do not remember having seen it used in connection with motor outputs. Referring more particularly to the design of 1,200-volt motors, as the author points out, there is very little data of their performance in practice. A new electric railway running between Manchester and Bury is, however, approaching completion, and will be worked by means of 200-h.p., series-wound, interpole, 1,200-volt motors, with shunted field for maximum speeds. These motors have behaved very satisfactorily on the tests, and though no data is yet available, they promise to give good results. No revolutionary changes in principles, but rather refinements in design, are required for the high-voltage motor; ample clearance around the commutator, the avoidance as far as possible on brush gear of corners and projections to which an arc might hang and accentuate the damage done by flash-overs, the use of solid mica insulation, thereby increasing the slot space-factor, are lines along which improvements have run, and I would point out in this connection that the section of the 200-kw. 1,200-volt motor shown in Fig. 13 would have to be very considerably

Mr. BARNES modified before it could be run successfully. No oiling arrangements are shown, and the space required for this has a considerable influence on the frame design and overall dimensions. The clearances of the commutator are altogether too small, in fact the barrel end-ring shown is short-circuiting the commutator bars. The author states that on a 1,200-volt motor the commutator is only half the length of that of the 600-volt motor of similar power. The point affecting the design, however, is not the length of the copper bar on which the brushes rest, but the length of the commutator casting; and when the requisite leakage distances to earth are made, the difference in length for the two voltages is very slight. It is bad policy to bring in the ventilating air immediately over the commutator, as the brush gear necessarily forms pockets

tically, instead of diagonally, and this in turn necessitates Mr. Barnes' more careful design of bearings, in order that the armature is not dropped on to the bottom pole-piece. The following are the principal particulars of the 200-h.p. 1,200-volt motor used on the Manchester-Bury electrification:—

Rated voltage ... ..	1,200
Efficiency (including gear) ...	87.5 %
Current ... ..	140 amperes
Speed, full field ... ..	500 r.p.m.
" , short field ... ..	600 r.p.m.

#### Armature.

Diameter ... ..	21½ in.
Core length ... ..	15 in.

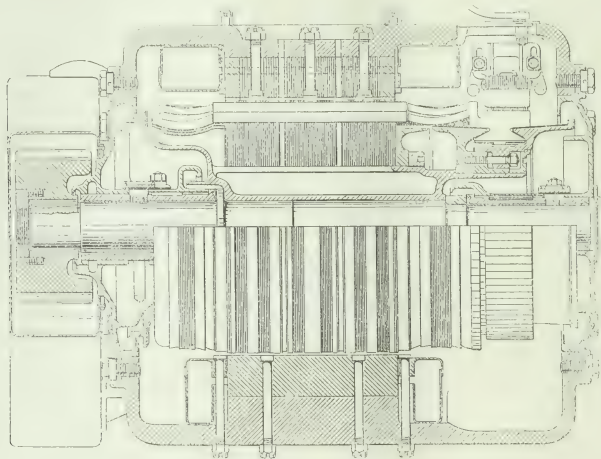


FIG. A.—Longitudinal section through 200-h.p. 1,200-volt motor.

in which any grit or dirt may collect, and this as a general rule is one of the weakest parts of the motor. The motor shown is evidently of a split-frame design. The general tendency in design at the present time is to use the solid frame owing to the difficulty of keeping the two halves solidly bolted together under the very heavy duty which they have to perform. If the two halves become loose it has an immediate and very detrimental effect on the bearings and bearing brackets, and after a long experience the split-frame type of motor has been discarded on the Liverpool and Southport section of the Lancashire and Yorkshire Railway, and is being replaced by the solid frame. In order to improve what might be termed the space factor under the cars, the tendency has been to place the main pole-pieces horizontally and ver-

Total conductors ... ..	708
Total slots ... ..	12
Area of conductor ... ..	0.26 sq. in.
Dimensions of conductor ...	0.65 in. x 0.4 in.
Slot space-factor ... ..	0.375

#### Commutator.

Working length ... ..	4.125 in.
Total length ... ..	5.375 in.
Diameter ... ..	20 in.
Number of segments ... ..	353
Width of segment including mica ... ..	0.178 in.
Poles per segment, average ...	1.376
Number of brushes per stud	2

Size of brush ... ..	$1\frac{1}{2}$ in. $\times$ 9/16 in.
Resistance of armature under brushes ... ..	0.2 ohm at 85° F.
Gear ratio ... ..	50 $\times$ 20
Diameter of car wheel ...	43 in.
Weight complete ... ..	7,800 lb.

This motor is able to give a schedule speed of 28 m.p.h. excluding stops on a section of line of very heavy gradients and stops 1½ miles apart. Figs. A and B herewith show the longitudinal section and cross-section of this motor.

Mr. R. T. SMITH: I should like to say a word or two from the general railway point of view rather than from

motor is a compromise, since it does not use the active Mr. Smith, material in the motor to the best advantage. All things considered, however, it is about the most satisfactory speed to-day, especially with a view to reducing gear losses to a minimum. If we look at Fig. 9 where speed increases as current decreases, we shall see that, as the speed increases, the losses decrease—except the gear loss which suddenly increases at about 100 amperes. I do not mean to say that because the speed increases therefore the losses decrease, but that increasing speed happens to be a measure of decreased losses. The author confines all his remarks to the series motor with “wheel-barrow” suspension and single-reduction gear. Such a motor is quite

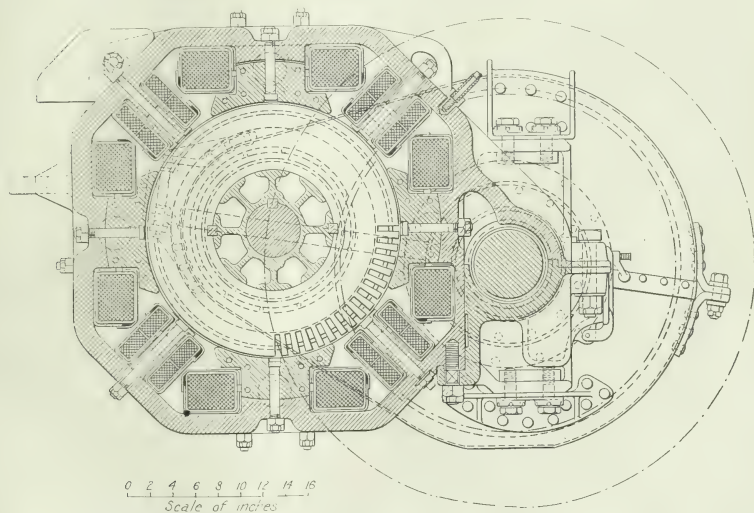


FIG. B.—Cross-section through 200-h.p. 1,200-volt motor.

the point of view of the motor designer. I agree with what Mr. Ferguson said as to the author's statement that an acceleration of  $1\frac{1}{2}$  m.p.h. per second should be considered to be a minimum. The author has put it too high if he is considering average acceleration where the lowest that should be asked for is about 1 m.p.h. per second. On page 451 the author refers to the free running speed of the 600-volt motor being about 1,000 r.p.m., which is 5,250 ft. per minute at the periphery of the armature, and speaks of this as if it were the limit. I venture to suggest that if we want to use the active material of the motor to the best advantage, instead of 5,250 ft. per minute being the limit of peripheral speed, this should be something between 8,000 and 9,000 ft. If that is true, the 600-r.p.m.

useful for suburban railway service and also for goods locomotive working, provided that the general speed of the motor train or goods locomotive never exceeds 60 miles per hour. We cannot use single-reduction gear with speeds above 60 miles per hour. Next he assumes without argument that the continuous-current series motor is the only form of continuous-current motor that can be used. It is perfectly true that the series motor stands an overload torque better than the shunt-wound motor, and with less commutation trouble, while it is much less liable to damage from variation of pressure, which is always met with in railway or tramway working. On the other hand there is the great disadvantage that the plain series motor is a 1-speed motor for a given load. Up to a

Mr. Smith.

certain date all the speed variations that could be obtained with the series motor were obtained by means outside the motor itself, by rheostatic and by series-parallel control. This was improved by the introduction of field control, which is not modern but only became practicable with the introduction of the commutating pole. As the author says, such variations of speed as are shown by Fig. 7 are only possible where commutating poles are used. Looking at it entirely from the railway point of view, the series-motor locomotive is, in my opinion, not yet comparable with the steam locomotive at speeds at which everybody's troubles begin, whether they are steam locomotive or electric locomotive engineers, that is at speeds above 60 miles per hour. The modern steam locomotive is such that it can give almost constant output with an enormous range of speed, from 15 miles per hour up to 80 or 90 miles per hour. The output at high speeds of the series electric motor falls off very sharply. To obtain an electric locomotive capable of hauling fast passenger traffic it must be equipped with motors unnecessarily powerful at low speeds, but, for everything that we have immediately in sight in this country in the way of railway electrification—that is to say, suburban and goods working—the continuous-current series motor with single-reduction gear is a satisfactory piece of apparatus now that it is equipped with commutating poles and field control. If field control is developed to any considerable extent, the series motor may be made suitable for all classes of goods service, and the economies to be effected in suburban railway service will be appreciable owing to the reduction of rheostatic losses during acceleration by the use of the short field. Field control is one of the two features recently introduced which makes the continuous-current series motor more acceptable for railway work. The other feature is regenerative control. That is being successfully applied in the United States on more than one electrified railway using continuous-current series motors. Its application is too recent for there to be any details available, but Mr. Storer will touch upon it to some extent in his coming paper. If, as I believe is true, something less than half the energy wasted in a stopping train by the application of the brakes can be returned to the supply by regenerative control,

economies in suburban working, at present badly wanted, will become possible by reducing the waste of energy which now goes on. This question then becomes important. Is the extra switchgear necessary to get field control and regenerative control with a continuous-current series motor going to make the equipment too complicated? To my mind the answer depends very much upon whether the various railways are willing to standardize supply voltages. Higher voltages than 600 have been fully dealt with by the author as they affect the motor, and they have been referred to by several speakers. The fact that we can have two motors permanently in series is another argument in favour of the series motor. On the Bury and Holcombe Brook railway a voltage of 3,600 is in use. Until quite recently that was the highest continuous-current railway voltage anywhere. On the line between Manchester and Bury 1,200 volts continuous current is in use, and 1,500 volts continuous current on the North-Eastern Railway. Personally I welcome all these experiments at different pressures because I hope that they will lead ultimately to the choice of the most suitable continuous-current voltage for the general average conditions in this country. When we are ready to decide what this pressure shall be, the railways will have to adopt it uniformly. We shall not get the advantages of regenerative control and field control if we have at the same time to contend with several different supply voltages. I should like to say something about the danger of comparing motors on only their 1-hour ratings. Fig. 8 shows that we cannot compare ventilated and unventilated motors for continuous running on the basis of their 1-hour ratings. There are still further difficulties in comparing a motor with a saturated field and a motor with an unsaturated field on their 1-hour ratings. This is clear from Figs. 4 and 5. In the Appendix the extract from the American Standardization Rules does not state what the temperature-rises are for continuous rating, and the inference is that they are 75 degrees C. This is not so, and the continuous-rating temperature-rises will be found in a separate table in the American Rules.

(Mr. PANNELL's reply to the discussion will be published in a later issue.)

# THE APPLICATION OF TELEPHONE TRANSMISSION FORMULÆ TO SKIN-EFFECT PROBLEMS.

By Professor G. W. O. Howe, D.Sc., Member.

(Paper first received 10 November, 1915, and in final form 21 January, 1916.)

## INTRODUCTION.

It is well known that at high frequencies the electric current is not distributed uniformly over the cross-section of conductors through which it flows. If the frequency is very high the current is confined to a very thin surface layer, and the resistance to such a current is consequently much greater than that of the same conductor to a continuous current or to an alternating current of a low frequency. The calculation of the depth of penetration can be found in Sir J. J. Thomson's "Recent Researches," chapter 4. In the present paper the problem is looked at from a somewhat different point of view, and is shown to be closely related to another problem with which many electrical engineers are more familiar.

When power is transmitted electrically by means of wires or cables, the power does not travel through the conductor itself, but through the space between and around the wires. The electric current flows through the conducting material and causes therein a continual dissipation of energy which must be drawn from the surrounding space; that is to say, some of the energy being transmitted is lost by being conducted sideways into the conductors, which may be said to levy toll on the energy transmitted by their aid. Inside the material of which the wire is made there is, therefore, a transmission of energy at right angles to the direction of the main transmission, but which is, none the less, governed by the same laws as the main transmission and capable of calculation by the same formulæ, if correctly applied.

A transmission line has four fundamental properties, viz. resistance, inductance, capacity, and leakage, the values of which per unit length may be represented by  $R$ ,  $L$ ,  $C$ , and  $G$  respectively. If  $Z$  is the impedance of unit length of the line,  $Z = R + j\omega L$ , where  $j = \sqrt{-1}$  and  $\omega = 2\pi f$ ; similarly if  $Y$  is the admittance of unit length,  $Y = G + j\omega C$ . If the transmission line is so long, or the losses so great, that the values of the current and potential difference at any point are not affected by reflection from the receiving end when an alternating potential difference is maintained at the sending end, then the potential difference or current at a point distant  $x$  from the sending end is equal to that at the sending end multiplied by  $e^{-ax}$ , where  $a^2 = ZY$ .

$ZY = (R + j\omega L)(G + j\omega C)$  and is a complex or vector quantity, and  $e^{-ax}$  gives both the amplitude and the phase of the current or potential difference at the given point. If the complex quantity  $\sqrt{ZY}$  be split up into its real and imaginary parts, we have  $\sqrt{ZY} = \beta + ja$ , and  $e^{-ax} = e^{-\beta x} \times e^{-ja x}$ . Now  $e^{-\beta x}$  is a proper fraction and gives the amplitude of the current or voltage at the point  $x$  in terms of the amplitude at the sending end, while  $e^{-ja x}$ , which is equal to  $\cos ax - j \sin ax$ , represents a vector of unit length rotated through an angle  $-ax$ . At

a distance  $x$  from the sending end, the phase of the potential difference or current lags behind that at the sending end by the angle  $ax$ .

## STRAIGHT CONDUCTORS.

Turning now to the problem of skin effect, we shall first consider the simple case in which the outward and return leads of an alternating-current transmission line consist of two very wide conducting strips placed face to face, but, of course, not actually in contact. This is the problem of the "slabs" considered on page 296 of "Recent Researches." We are not now concerned with the ordinary

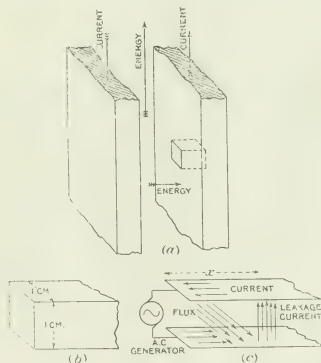


FIG. 1.

transmission of power, but with a transmission at right angles to it, viz. normally into one of the conducting strips. We need only consider the transmission of energy through a square of 1 cm. side in the surface of the plate, and along the square column of material of which this forms the base [Fig. 1 (a)]. Now this can be regarded as a transmission line of which the upper and lower surfaces, assumed to have no resistance, act as the outward and return leads, while the intervening conducting material replaces the dielectric, as shown in Figs. 1 (b) and 1 (c). Each square centimetre column of the conductor can thus be considered separately and assumed to have its own generator to maintain the potential difference between its opposite faces and to supply the energy which is dissipated within it.

Since our "dielectric" is a conductor, the leakage is enormous and we may safely neglect the capacity in comparison therewith. The inductance  $L$  of this line, consisting of two parallel strips 1 cm. wide and 1 cm. apart, is  $4\pi\mu/10^9$  henries per cm., where  $\mu$  is the permeability of the material. The leakage  $G$  per cm. is  $1/\rho$ , where  $\rho$  is the specific resistance of the material. Substituting these values we have

$$\sqrt{(ZY)} = \sqrt{(R + j\omega L)(G + j\omega C)} = \sqrt{(j\omega L G)} = \beta + ja$$

$$\text{or } j\omega L G = \beta^2 - \alpha^2 + 2ja\beta;$$

$$\text{whence } \alpha = \beta; 2ja\beta = \omega L G;$$

$$\text{and } a = \beta = \sqrt{\frac{1}{2}\omega L G} = 2\pi\sqrt{\frac{f\mu}{10^9}\rho} \quad (1)$$

Hence, if the root-mean-square value of the potential difference between the two imaginary strips 1 cm. apart is  $E_s$  at the sending end, that is, at the surface of the conductor, the value  $E$  at a depth  $x$  will be  $E_s e^{-\beta x}$ . The leakage current between the strips will be  $E/G$  or  $E/\rho$  per cm. Although this is the leakage current of the imaginary transmission line into the material, it is in reality the actual current density in the material at this depth. Hence the current density falls off in amplitude proportionally to  $e^{-\beta x}$ , where  $\beta = 2\pi\sqrt{(f\mu/10^9)\rho}$ . For copper  $\mu = 1$ ,  $\rho = 1.7 \times 10^{-6}$ , and  $\beta = 0.152\sqrt{f}$ . If  $f = 10^6$ ,  $\beta = 152$ , and the current density at a depth  $x$  is  $e^{-152x}$  of that at the surface. At a depth of  $1/15$  mm.,

$$e^{-152x} = e^{-1} = 0.37.$$

The following table gives the depth of penetration into copper at various frequencies; the last column will be referred to later.

TABLE 1.

$f$	$\beta$	Depth at which the Current Density is reduced to		Equivalent Thickness of Skin
		0.01	0.1	
		mm.	mm.	mm.
$10^6$	152	0.3	0.15	0.006
$10^5$	48	0.95	0.5	0.21
$10^4$	15.2	3.0	1.5	0.66
$10^3$	4.8	9.5	5.0	2.1
$10^2$	1.52	30	15	6.6

Exactly the same result would be obtained for a column adjoining the one just considered, say, for example, the one immediately above it. The lower face of this new column would coincide with the upper face of the one just considered, and the fictitious "line" currents in this common interface would be exactly equal and opposite at every moment. Hence there are no resultant currents in the direction of penetration. If there were, the assumption that our imaginary transmission lines have no resistance would not be permissible. The method is based on the assumption that the potential difference and current at the surface of one column are in phase with those at the surface of the next column, i.e. that there is no change of

phase in the direction of the main current and power transmission. Although this assumption of quasi-stationary conditions is usually made in skin-effect problems, it is not strictly true, and would lead to erroneous results if applied to cases in which the depth of penetration is comparable with the wave-length of the main transmission, since in such cases the normal component of the current would be comparable with the longitudinal component. In all ordinary cases, however, no change in the conditions would result from laminating the conductors in a direction at right angles to the flow of current, if the laminations were merely separated by infinitely thin layers of an infinitely good conducting material. This is the assumption here made, and these infinitely thin layers of a perfect conductor constitute the fictitious lines by means of which energy is transmitted into the copper or other material.

Considering now the phase of the current at various depths, it has been shown that the change of phase, taking the conditions at the surface as the standard of reference, will be  $\alpha x$ . The phase will have gone through a complete cycle when  $\alpha x = 2\pi$ , i.e. when  $x = 2\pi/\alpha = \sqrt{(10^9\rho/f\mu)}$ , which for copper at a frequency of a million will be 0.04, that is 0.4 mm. This then is the wave-length of the transmission into the conductor. At the moment when the current at the surface has its maximum value, it will be zero at a depth of 0.1 mm., while between 0.1 and 0.3 mm. what current there is will be flowing in the opposite direction. The total current will not have its maximum value at the same moment as the current at the outer surface. It can be shown that the phase of the surface current is  $45^\circ$  ahead of the total current, for it is well known that the apparent impedance at the sending end of a non-reflecting transmission line is  $\sqrt{(Z/Y)}$ , which in the present case is  $\sqrt{(j\omega L/G)}$  or  $\sqrt{(j\omega L/G)/45^\circ}$ .

Hence, the fictitious "line" current entering normally into the conductor lags  $45^\circ$  behind the surface potential difference, with which, however, the surface current is in phase.

In what follows, all actual currents, i.e. the leakage currents of the fictitious lines, will be designated by  $I$ , whereas the fictitious line currents flowing normally into the material will be designated by  $i$ . The fictitious line current  $i_s$  at the surface must be equal to the resultant leakage current of our imaginary transmission line, i.e. to the actual total current  $I$  flowing through the conductor per cm. of width. The fictitious line current at any depth  $x$  is therefore given by the formula

$$i_x = I_{\max} e^{-\beta x} \cos(\omega t - \beta x - 45^\circ)$$

where the sending potential difference is given by the formula

$$v = v_{\max} \cos \omega t$$

If  $I_x$  is the leakage current density at a depth  $x$

$$I_x = -\frac{d i}{d x} = -\beta I_{\max} e^{-\beta x} [\sin(\omega t - \beta x - 45^\circ) + \cos(\omega t - \beta x - 45^\circ)]$$

At the surface  $x = 0$ , and

$$I_s = -\beta I_{\max} [\sin(\omega t - 45^\circ) + \cos(\omega t - 45^\circ)] \\ = \beta I_{\max} 2 \sin 45^\circ \cos \omega t$$

and

$$I_{\rho \max} = \sqrt{2} \beta I_{\max}$$

$$\text{or } I = I_s / \sqrt{2} \beta \text{ [R.M.S. values]} \quad (2)$$

where  $I$  is the total current per cm.-width of the conductor and  $I_s$  is the current density at the surface. The power dissipated in the column of 1 sq. cm. cross-section is

$$P = \int_0^{\infty} I_s^2 \rho \, d\epsilon = I_s^2 \rho \int_0^{\infty} e^{-2\epsilon/t} d\epsilon = I_s^2 \rho \cdot \frac{1}{2} t \quad (3a)$$

where  $I_s$  is the root-mean-square value of the leakage current per sq. cm. at the depth  $x$ .

If the total current  $I$  were uniformly distributed over a layer of depth  $t$ , the power dissipated would be  $I^2 \rho / t$ , and by equating this to the actual power dissipated, the equivalent depth  $t$  can be found, which, with uniform current distribution would give the same losses as those actually occurring in the strip; thus from Equations (2) and (3a)

$$\frac{I_s^2 \rho}{t} = \frac{I^2 \rho}{2 \cdot 3 t} = \frac{I_s^2 \rho}{2 \cdot 3}$$

$$t = \frac{1}{3} = \frac{1}{2 \cdot \pi} \sqrt{\left( \frac{10^9 \rho}{t \mu} \right)} \quad (4)$$

The power dissipated and the equivalent depth  $t$  can be found in another way; the power dissipated in the column must be equal to the power supplied at the sending end of the fictitious transmission line, and

$$P = v_s i_s \cos \phi$$

Now  $v_s/i_s$  is the sending-end impedance and is equal to  $\sqrt{(Z/Y)}$ , which in this case is equal to  $\sqrt{(\omega L/G)}/45^\circ$ . Therefore

$$P = i_s^2 \sqrt{(\omega L/G)} \cos 45^\circ = i_s^2 / \sqrt{2} \cdot 3 G \cdot (1/2) = i_s^2 \beta \rho \quad (3b)$$

Equating this to  $i_s^2 \rho / t$  we get  $t = 1/\beta$  as before.

It has been assumed that the penetration is so small compared with the thickness of the conductor that the current density is reduced to a negligible amount before reaching the outer surface of the slabs or strips. If this is not so—and it will not be so if the strips are very thin or the frequency low—the formulae to be applied are those for transmission lines of a definite length. It can be seen from Table 1 that the simple formula can be applied to copper strips down to a thickness of 0.5 mm. for the frequencies employed in radio-telegraphy.

#### CONDUCTORS IN WHICH THE CURRENT IS CONFINED TO A THIN SURFACE LAYER.

The same formula can be applied to any conductor, not too near the return lead, if the value of  $t$  is small compared with the minimum dimension of the cross-section. If, however, the penetration is comparable with this minimum dimension, the formula no longer holds, because the inductance and leakage of our fictitious transmission line into the material change as the centre of the wire is approached.

If in a round wire the penetration is small, the ratio of the effective to the total cross-section is

$$\frac{2 \cdot \pi r \left( 1 - \frac{1}{2} t/l \right)}{\pi r^2} = \frac{2 \cdot 3 r - 1}{\beta^2 r^2}$$

$$\text{Therefore } R_c = \frac{\beta^2 r^2}{2 \cdot 3 r - 1} = \frac{\beta^2 r^2 (2 \cdot 3 r + 1)}{4 \cdot 5 r - 1}$$

where  $R_c$  is the resistance to steady currents, and  $R_f$  the resistance to high-frequency currents.

If the penetration is small, as we have assumed,  $4 \beta^2 r^2$  will be very large compared with unity, so that we have approximately,

$$\left. \begin{aligned} R_c/R_f &= \frac{1}{2} \beta r + 0.25 \\ &= \pi r \sqrt{\left( \frac{10^9 \rho}{t \mu} \right)} + 0.25 \end{aligned} \right\} \quad (5)$$

This formula is usually given without the constant term 0.25, and is referred to as Lord Rayleigh's formula for very high frequencies. As given here it can be safely used if the value of  $R_c/R_f$ , calculated by it, exceeds 1.75, the error in that case not exceeding 1 per cent.

*Example 1.*—For copper at a frequency of  $10^6$ , we have

$$t = \frac{1}{\beta} = \frac{1}{2 \cdot \pi} \sqrt{\left( \frac{10^9 \times 1.7}{10^6 \times 10} \right)} = \frac{1}{152} \text{ cm.} = 0.0066 \text{ mm.}$$

$$R_c/R_f = \frac{1}{2} \beta r + 0.25 = \frac{1}{2} (152 r) + 0.25 = 76 r + 0.25,$$

where  $r$  = radius of wire in cm.

The formula is applicable at this frequency to any copper wire with a diameter exceeding  $\frac{1}{8}$  mm.

*Example 2.*—Steel rails,  $f = 50$ ,  $\rho = 20 \times 10^{-6}$  ohms per cm. cube. Assuming  $\mu = 1,000$ ,

$$a = \beta = 2 \cdot \pi \sqrt{\left( \frac{t \mu}{10^9 \rho} \right)} = 2 \cdot \pi \sqrt{\left( \frac{50 \times 1,000}{10^9 \times 20 \times 10^{-6}} \right)} = 10$$

$$t = 1/\beta = 0.1 \text{ cm.}$$

Knowing the equivalent depth of penetration and the periphery, the effective resistance can be calculated. If the frequency be reduced to 25,  $t$  becomes 1.4 mm., since it is inversely proportional to the square root of the frequency. This agrees with measurements made by Villiers and Boucherot,<sup>2</sup> who found that, at frequencies between 15 and 30, correct results were obtained by assuming the current to be confined to a skin of 1.3 to 1.9 mm.

The high-frequency resistance of any conductor can be found in the same way, provided that the minimum dimension of its cross-section is not less than about six times the equivalent depth  $t$  of penetration, and that the return conductor is far removed. The case of coiled conductors is considered later.

#### ROUND WIRES IN WHICH THE CURRENT IS NOT CONFINED TO A THIN SURFACE LAYER.

In this case the characteristics, *i.e.* the inductance and leakage per cm. of the fictitious transmission lines into the conductor, are not constant but vary with the distance from the centre, and the ordinary telephone transmission formulae are no longer applicable. The fictitious lines of infinite conductivity are now two parallel discs, 1 cm. apart, carrying radial currents, while the magnetic flux is concentric about the axis. The inductance of the "line" in henries per radial cm. is

$$\frac{2}{10^9} \mu$$

or  $l/x$  where  $l = \mu(2/10^9)$ , and  $x$  is the distance from the receiving end, that is, from the centre of the wire. The

<sup>2</sup> *Science Abstracts*, vol. 15 B, p. 244, 1912.

leakance per radial cm. is  $g/x$ , where  $g = 2\pi\rho$ . For the loss of current due to leakance we have

$$\frac{dI}{dx} = v \cdot g/x$$

and for the drop of voltage along the "line" we have

$$\frac{dv}{dx} = \frac{I}{v} \cdot \frac{dI}{dx} = j\omega \frac{I}{v}$$

assuming that the current is a sine function of the time. Hence

$$\begin{aligned} \frac{d^2v}{dx^2} &= j\omega \frac{I}{v} \cdot \frac{dI}{dx} - j\omega \frac{I}{v} \\ &= j\omega \frac{I}{v} \cdot g \cdot v - \frac{I}{v} \cdot \frac{dv}{dx} \end{aligned}$$

and

$$\frac{d^2v}{dx^2} + \frac{1}{v} \cdot \frac{dv}{dx} + kv^2 = 0$$

where

$$k^2 = -j\omega I g = -j\omega 4\pi\rho I 10^9$$

and

$$k = \sqrt{-j} \sqrt{\left(\frac{8\pi^2 I \rho}{10^9}\right)} = (1-j)\beta$$

where  $\beta = 2\pi\sqrt{(I\rho 10^9)}$  (see Equation 1)

Hence

$$k = \sqrt{2}\beta/45^\circ$$

The current density at any point in the wire is equal to the potential difference between the two parallel discs at

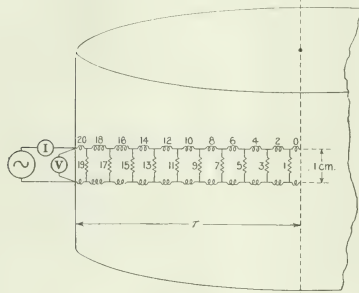


Fig. 2.

that point divided by the specific resistance of the material, that is, to  $v_x/\rho$ . Hence, if  $I_x$  be the current density, we have

$$\frac{dI}{dx} + \frac{1}{v} \cdot \frac{dv}{dx} + k^2 I = 0.$$

The solution of this equation can be given in terms of Bessel Functions.\*

The problem can be solved for any particular case, however, without employing higher mathematics, by applying the graphical method so commonly employed in telephone

transmission problems. The line is divided into a definite number of sections by assuming its leakage and capacity to be concentrated at a number of equidistant points. The current and potential difference at the receiving end are assumed, and those at any part of the line determined by constructing a vector diagram section by section, commencing at the receiving end and gradually working back along the line. The accuracy will depend on the fineness of the assumed subdivision of the line.

This method has been employed by the author to determine the distribution of current in straight cylindrical conductors at high frequencies, and two examples are here given.

**Example 1.**—Round copper rod 2 cm. diameter at a frequency of 1,590.  $\omega = 2\pi f = 10,000$ . This will also be applicable to any copper wire for the same value of  $d\sqrt{f}$ , viz. 79; for example, a 2 mm. wire at a frequency of 159,000. It will also be applicable to a wire of any material for the same value of  $\pi r\sqrt{(f\mu 10^9)}$ , viz. 3'04.

The inductance per radial cm. =  $\frac{2}{10^9} \cdot \frac{1}{x}$  henry. The leakance per radial cm. =  $3.7 \times 10^6 \times x$  ohms<sup>-1</sup>. These values refer to a disc 1 cm. thick in which  $x$  is the distance from the axis of the wire. As shown in Fig. 2 the total distance of 1 cm. from the sending end of our fictitious line, which is the outside surface of the wire, to the receiving end, which is the centre, has been divided into 10 sections each 1 mm. long, with the leakance of each section concentrated at its mid-point. Each section is in reality an annular ring 1 mm. wide. The inductance of each section is  $\frac{2}{10^9} \cdot \frac{1}{x}$ , while its leakance is  $3.7 \times 10^6 \times x$ .

Since there is no outlet for the current at the centre, the line is on open-circuit, and the received current zero. If we assume the potential difference at the receiving end  $V$ , to be  $10^{-5}$  volts and gradually work back along the line, we obtain Fig. 3 and find by measurement that at the sending end the line current is 292 amperes and the applied potential difference  $71.75 \times 10^{-5}$  volts. The component of the potential difference in phase with the current is  $47.9 \times 10^{-5}$  volts, and if we divide this by the current we get  $1.64 \times 10^{-6}$  ohms as the high-frequency resistance per cm. of this 2-cm. copper rod. Its resistance to continuous currents is  $0.541 \times 10^{-6}$  ohms, which gives  $R_f/R_c = 3.035$ . From formula (5)  $R_f/R_c = 3.29$ . This difference is due to the assumption of concentrated inductance and leakance.

Although of interest in showing clearly the variation in current density and phase throughout the conductor, the graphical construction is quite unnecessary for the determination of  $R_f/R_c$  for such large values of  $d\sqrt{f}$ . It is fortunate that the graphical method only becomes unwieldy and inaccurate (unless the subdivision is carried farther than the ten sections employed in Figs. 3 and 4) for large values of  $d\sqrt{f}$ , where it is no longer required. If  $d\sqrt{f}$  exceeds about 40, formula (5) can be used, with an accuracy of 1 per cent, while for smaller values of  $d\sqrt{f}$  the graphical method is very convenient and accurate. One would not apply the method to each individual problem as it arose, but merely to three or four typical cases lying between  $d\sqrt{f} = 10$  and  $d\sqrt{f} = 40$ ; the results could then be plotted and the curve used to find the value of  $R_f/R_c$  for any other value of  $d\sqrt{f}$ . This curve is shown in Fig. 5.

\* See Lord Kelvin's "Mathematical and Physical Papers," III, p. 173.

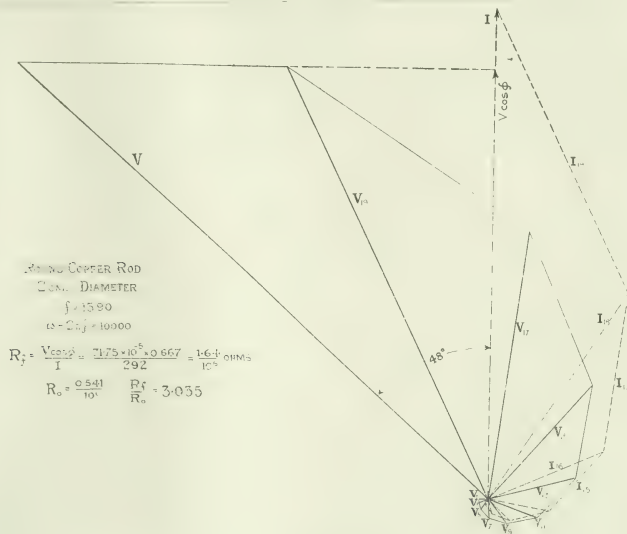


FIG. 3.

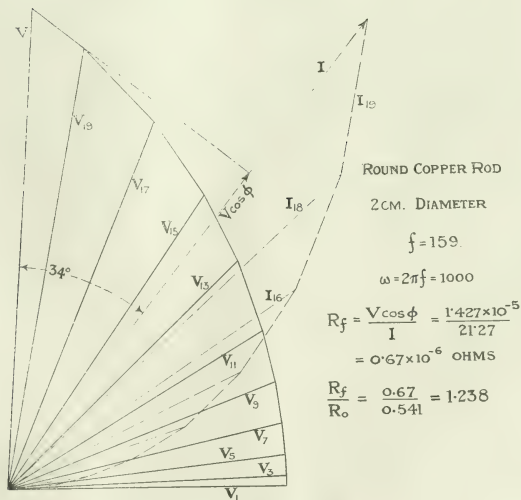


FIG. 4.

**Example 2.**—Round copper rod 2 cm. diameter;  $f = 150$ ;  $\omega = 2\pi f = 1,000$ ;  $d\sqrt{f} = 25.22$ ;  $\pi r\sqrt{(1/\mu)(10^{-9})} = 0.059$ .

The vector diagram (Fig. 4) is constructed exactly as before and gives a sending-end line current of  $21.27$  amperes and an applied potential difference of  $1.72 \times 10^{-5}$  volts, the angle between them being  $34^\circ$ . The component of the potential difference in phase with the current is  $1.427 \times 10^{-5}$  volts, and the high-frequency resistance

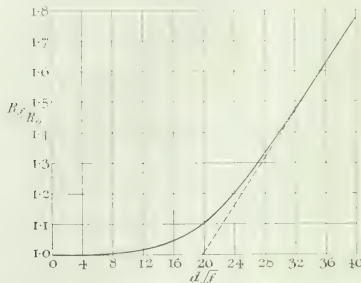


FIG. 5.

Resistance to alternating current for straight round copper wire.  
Resistance to continuous current

$$\text{If } d\sqrt{f} \text{ exceeds } 22, R_d/R_0 = 0.038 d\sqrt{f} + 0.25.$$

therefore  $0.67 \times 10^{-6}$  ohms. Hence  $R_d/R_0 = 1.238$ , which only differs by one-third of 1 per cent from the value calculated from the formulae involving Bessel Functions.\*

#### COILED CONDUCTORS.

As a further illustration of the application of the method, we shall now consider the case of a solenoid, closely wound with a single layer of rectangular wire. If the wire is of small radial thickness, or the frequency comparatively low, or the specific resistance high, the current may extend with varying density throughout the whole cross-section. From the point of view of the transmission of energy normally into the conductor, it is analogous to a transmission line of definite length, open at the far end, the far end in this case being the outer surface of the conductor, and the length of the transmission line the radial depth of the wire with which the coil is wound. If, as we are now assuming, the electromagnetic energy is not entirely dissipated before reaching the end of the line, the electromagnetic wave is reflected and gives rise to a wave travelling back along the line, i.e. radially inwards in our coiled conductor, this reflected wave being superposed upon the forward or outward wave.

The formulae for this case are well known to telephone engineers and those concerned with long-distance power transmission. We shall now apply these formulae to this special case. We shall consider a coil closely wound with rectangular wire, and assume the magnetic field to be parallel to the coil axis, which will be true except near the ends. The transmission of energy into the material will

therefore be radially outwards as shown in Fig. 6, where a piece of the conductor is drawn to a larger scale, with two imaginary planes which act as the outward and return leads for the outward transmission of energy. Such planes if very thin and of infinitely good conducting material could be actually present without in any way affecting the coil. The leakage current between these planes is really the main current flowing round the coil, the distribution of which we have to determine in order to find the high-frequency resistance. We shall assume the planes to be 1 cm. apart and neglect the slight want of parallelism between them, and we shall consider a length of 1 cm. parallel to the axis of the coil. We shall denote by  $i$  the



FIG. 6.

fictitious "line" currents in the radial planes, by  $I$  the leakage current per sq. cm. between them, and by the suffixes  $s$  and  $r$  the sending and receiving ends of the line, i.e. the inside and the outside surfaces of the conductor. Now  $i_r = 0$ , because the transmission line comes to an abrupt end on reaching the outer surface, and  $i_s$  is equal to the total leakage current between the planes, i.e. to the total actual current flowing in the coil per axial centimetre.

Let  $V_r =$  P.D. between the planes at the receiving end,  
 $V_s =$  " " " " " sending end,  
and  $\tau =$  radial depth of the conductor,

then the voltage and current at a distance  $x$  from the open end of the line are given by

$$V = V_r \cosh x \sqrt{(ZY)} = \frac{1}{2} V_r (e^{x\sqrt{(ZY)}} + e^{-x\sqrt{(ZY)}})$$

and

$$i = V_r \sqrt{(Y/Z)} \sinh x \sqrt{(ZY)} = \frac{1}{2} V_r \sqrt{(Y/Z)} (e^{x\sqrt{(ZY)}} - e^{-x\sqrt{(ZY)}}).$$

To find the current at the sending end, we put  $x = \tau$  and get

$$i_s = \frac{1}{2} V_r \sqrt{(Y/Z)} (e^{\tau\sqrt{(ZY)}} - e^{-\tau\sqrt{(ZY)}}).$$

Putting

$$\sqrt{(ZY)} = \beta + j\alpha \quad \text{and} \quad \sqrt{Z} = \sqrt{\left(\frac{G}{\omega L}\right)} = \frac{1}{\sqrt{2}\beta} \angle 45^\circ$$

(since  $G = 1/\rho$ ;  $L = 4\pi\mu/10^9$  and  $\alpha = \beta = \sqrt{\frac{1}{2}\omega L(G)}$ ) we get

$$i_s = \frac{1}{2} V_r \cdot \frac{1}{\sqrt{2}\beta} \cdot \frac{1}{\sqrt{2}\beta} (e^{\beta\tau} - e^{-\beta\tau}) \cos \beta\tau + j (e^{\beta\tau} + e^{-\beta\tau}) \sin \beta\tau$$

$$\text{or } i_s = \frac{1}{2} V_r \cdot \frac{1}{\sqrt{2}\beta} [(e^{\beta\tau} + e^{-\beta\tau}) + 2(\sin^2 \beta\tau - \cos^2 \beta\tau)] \angle \phi - 45^\circ$$

$$\text{where } \tan \phi = \frac{(e^{\beta\tau} + e^{-\beta\tau}) \sin \beta\tau}{(e^{\beta\tau} - e^{-\beta\tau}) \cos \beta\tau} = \frac{\cosh \beta\tau \sin \beta\tau}{\sinh \beta\tau \cos \beta\tau}$$

It should be noted that  $i_s$  is equal to the actual total current  $I$  flowing round the coil per axial centimetre, and

\* The possibility of treating skin-effect problems graphically was pointed out by Dr. Hay in 1910 (*Journal I.E.E.*, vol. 49, p. 487, 1911).

that  $V_r/\rho$  is equal to the current density  $I_r$  at the outer surface of the conductor. From the above equation we have therefore that

$$I_r = I_0 \frac{8\beta^2}{e^{2\beta\tau} + e^{-2\beta\tau} - 2\cos 2\beta\tau}$$

Similarly it can be shown that the current density  $I_r$  at the inner surface is given by the formula

$$I = \frac{1}{2} I_0 \sqrt{(e^{2\beta\tau} + e^{-2\beta\tau} + 2\cos 2\beta\tau) \theta}$$

where  $\tan \theta = \tan \beta\tau \tanh \beta\tau$ .

$$\text{Hence } I = I_0 \cdot 2\beta^2 \frac{e^{2\beta\tau} + e^{-2\beta\tau} + 2\cos 2\beta\tau}{e^{2\beta\tau} + e^{-2\beta\tau} - 2\cos 2\beta\tau}$$

When  $\beta\tau$  is very large this reduces to the formula for the case of small penetration, viz.  $I_r = \sqrt{2}\beta I_0$ .

For the power dissipated in the conductor we have

$$P = \int_0^{\tau} \frac{V_r^2}{\rho} dx$$

where  $V$  is the R.M.S. value of the potential difference between the fictitious transmission lines at the distance  $x$  from the outer surface. Now

$$V = \frac{1}{2} V_0 \sqrt{(e^{2\beta x} + e^{-2\beta x} + 2\cos 2\beta x) \theta'}$$

where  $\tan \theta' = \tan \beta x \tanh \beta x$ .

$$\begin{aligned} \text{Hence } P &= \frac{V_0^2}{4\rho} \int_0^{\tau} (e^{2\beta x} + e^{-2\beta x} + 2\cos 2\beta x) dx \\ &= \frac{V_0^2}{8\rho\beta} (e^{2\beta\tau} - e^{-2\beta\tau} + 2\sin 2\beta\tau) \end{aligned}$$

If  $l$  is the equivalent radial thickness, which, with uniform distribution of the current, would give the same dissipation of energy,

$$P = I_0^2 l$$

Now equating these two values of  $P$ , and substituting for  $I$  its value in terms of  $V_0$ , we have

$$\frac{V_0^2}{8\beta\rho} \cdot \frac{\rho}{l} (e^{2\beta\tau} + e^{-2\beta\tau} - 2\cos 2\beta\tau) = \frac{V_0^2}{8\rho\beta} (e^{2\beta\tau} - e^{-2\beta\tau} + 2\sin 2\beta\tau)$$

$$\begin{aligned} \text{or } l &= \frac{1}{\beta} \frac{e^{2\beta\tau} + e^{-2\beta\tau} - 2\cos 2\beta\tau}{e^{2\beta\tau} - e^{-2\beta\tau} + 2\sin 2\beta\tau} \\ &= \frac{1}{\beta} \frac{\cosh 2\beta\tau - \cos 2\beta\tau}{\sinh 2\beta\tau + \sin 2\beta\tau} \end{aligned}$$

For large values of  $2\beta\tau$  this reduces to  $1/\beta$ , as already found for small penetration; and for very small values of  $2\beta\tau$ ,  $l$  approximates to  $\tau$ .

For all cases, we have

$$\begin{aligned} R_c &= \frac{\tau}{\gamma} \\ R_c &= l = \gamma \end{aligned}$$

where  $R_c$  is the high-frequency resistance of the coil, and

$$\gamma = \frac{\cosh 2\beta\tau - \cos 2\beta\tau}{\sinh 2\beta\tau + \sin 2\beta\tau}$$

By expanding the terms in series, this may be written

$$\begin{aligned} R &= \frac{1 + \frac{2}{3}\beta^2\tau^2 + \frac{2}{15}\beta^4\tau^4 + \dots}{1 + 2\frac{2}{3}\beta^2\tau^2 + 2\frac{2}{15}\beta^4\tau^4 + \dots} \quad \text{where } \beta = 2\beta\tau, \end{aligned}$$

which for small values of  $\beta$ , i.e. for low frequencies, reduces to

$$\frac{R_c}{R} = 1 + \frac{2}{3} \frac{\tau^2}{5!}$$

For copper this may be written,

$$R/R_c = 1 + 47.5 \times 10^{-10} (\tau/\text{ft})^4.$$

Equivalent formulæ have been obtained by Wien and Sommerfeld\* by other methods.

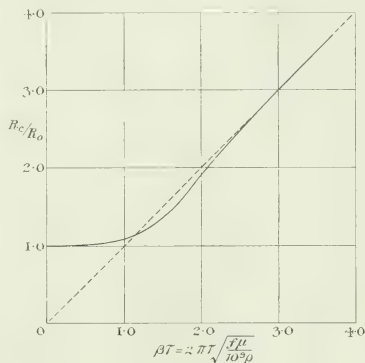


FIG. 7.

The values of  $R_c/R_0$  calculated from the accurate formula  $R_c/R_0 = \beta\tau/\gamma$  for different values of  $\beta\tau$  are given in Table 2 and are plotted in Fig. 7. These results are not only

TABLE 2.

Single-layer Solenoid; Rectangular Wire; Closely Wound.

$\beta\tau$	$\gamma = \frac{\cosh 2\beta\tau - \cos 2\beta\tau}{\sinh 2\beta\tau + \sin 2\beta\tau}$	$\tau/\lambda$ (copper)	$\frac{R}{R_c}$
0.05	0.050	0.320	1
0.1	0.100	0.658	1
0.2	0.200	1.316	1
0.3	0.300	1.974	1
0.4	0.400	2.632	1
0.5	0.499	3.290	1
0.6	0.594	3.948	1.011
0.7	0.685	4.606	1.022
0.8	0.772	5.264	1.037
1.0	0.921	6.58	1.086
1.25	1.045	8.225	1.196
1.5	1.09	9.87	1.376
2.0	1.054	13.16	1.807
2.5	1.01	16.45	2.475
3.0	0.996	19.74	2.988

\* *Annalen der Physik*, vol. 15, p. 687, 1904; vol. 14, p. 16, 1904; vol. 24, p. 622, 1907.

applicable to single-layer solenoids closely wound with rectangular wire, but also to hollow tubular straight conductors with a radial thickness  $\tau$  not exceeding about one-third of the radius. They are also applicable to the case first considered, viz. two wide parallel strips or slabs, if the penetration is such that the current is distributed throughout the whole thickness of the strips.

Although we have determined the equivalent resistance by considering the distribution of current throughout the conductor, it can be found without any such consideration. This is a striking example of the advantage of the point of view here adopted and the method developed in this paper. It has been shown that the sending current  $i_s$  of our fictitious transmission line into the material is equal to the total actual current in the conductor, and knowing the apparent impedance  $Z_s$  at the sending end of the line, it is a simple matter to calculate the power transmitted into, and therefore dissipated within, the conductor. Thus, we have shown that

$$i_s = \frac{V_s}{2\beta\mu} \sqrt{(\cosh 2\beta\tau - \cos 2\beta\tau)} |\phi - 45^\circ$$

and  $V_s = (V/\sqrt{2}) \sqrt{(\cosh 2\beta\tau + \cos 2\beta\tau)} |\theta$  where  $\tan \phi = (\tan \beta\tau)/(\tanh \beta\tau)$  and  $\tan \theta = \tan \beta\tau \tanh \beta\tau$ .

$$\text{Therefore } i V = i_s^2 \sqrt{2\beta\mu} \sqrt{\frac{(\cosh 2\beta\tau + \cos 2\beta\tau)}{(\cosh 2\beta\tau - \cos 2\beta\tau)}}$$

$$\text{and } \cos \{\theta - (\phi - 45^\circ)\} = \frac{\sinh 2\beta\tau + \sin 2\beta\tau}{\sqrt{2} \sqrt{(\cosh^2 2\beta\tau - \cos^2 2\beta\tau)}}$$

and the power, which is equal to the product of  $i_s$  and  $V_s$  multiplied by the cosine of the angle between them, is

$$P = i_s^2 \sqrt{2\beta\mu} \sqrt{\frac{(\cosh 2\beta\tau + \cos 2\beta\tau)}{(\cosh 2\beta\tau - \cos 2\beta\tau)}} \cdot \frac{\sinh 2\beta\tau + \sin 2\beta\tau}{\sqrt{2} \sqrt{(\cosh^2 2\beta\tau - \cos^2 2\beta\tau)}} \\ = i_s^2 \frac{\beta\mu}{\gamma}$$

Hence the high-frequency resistance

$$R_i = \frac{\beta\mu}{\gamma} \quad \text{and} \quad \frac{R}{R_0} = \frac{\beta\tau}{\gamma}$$

as previously found by integrating throughout the conductor.

## AN INVESTIGATION INTO THE MAGNETIC BEHAVIOUR OF IRON AT VERY HIGH FREQUENCIES WITH THE AID OF A POULSEN-ARC GENERATOR.

By N. W. McLACHLAN, B.Sc. Eng., Associate Member.

(Paper received 17 February, 1916.)

### INTRODUCTION.

It has been shown by Alexanderson,<sup>\*</sup> Jouaust,<sup>†</sup> and Schames<sup>‡</sup> that iron responds to high-frequency alternating magnetization, and that the true permeability is similar to that at frequencies of 50 periods per second. The highest frequency attained by Alexanderson was  $2 \times 10^5 \sim$  by means of an alternator running at  $2 \times 10^4$  p.m. Schames attained a frequency of the same order of magnitude by using a high-frequency arc generator, the arc burning in a Bunsen flame, whilst Jouaust obtained a frequency of  $10^5 \sim$  by means of a Poulsen-arc generator.

The object of the present experiments was to extend the range of frequency to  $10^6 \sim$  utilizing a Poulsen arc generator capable of developing about  $\frac{1}{2}$  kw. of high-frequency power. The materials tested were Stalloy (silicon iron) and Lohys (mild steel or pure iron) plates of different thicknesses.

### DETAILS OF RINGS AND WINDINGS.

	Silicon Iron (1)	Silicon Iron (2)
No. of discs ... ..	10	5
Total thickness of discs ...	0.25 cm.	0.235 cm.
Mean " 1 disc ... ..	0.25 mm.	0.47 mm.
Radial width of 1 disc ...	0.635 cm.	0.953 cm.
Cross-sectional area of core	0.159 sq. cm.	0.224 sq. cm.
Mean diameter of core ...	9.53 cm.	9.21 cm.
No. of turns on core ... ..	270	288
(0.25 mm. diam., 9 in parallel)		(9 in parallel)
$H_{\text{max}}$ ... ..	1.78 I.E.M.S.	1.98 I.E.M.S.
	Pure Iron (3)	Pure Iron (4)
No. of discs ... ..	18	7
Total thickness of discs ...	0.45 cm.	0.265 cm.
Mean " 1 disc ... ..	0.25 mm.	0.38 mm.
Radial width of 1 disc ...	0.635 cm.	0.953 cm.
Cross-sectional area of core	0.286 sq. cm.	0.252 sq. cm.
Mean diameter of core ...	9.53 cm.	9.21 cm.
No. of turns on core ... ..	270	288
(9 in parallel)		(9 in parallel)
$H_{\text{max}}$ ... ..	1.78 I.E.M.S.	1.98 I.E.M.S.

\* E. F. W. ALEXANDERSON: "Magnetic Properties of Iron at Frequencies up to 200,000 Cycles," *Transactions of the American Institute of Electrical Engineers*, vol. 30, p. 2433, 1911.

† R. JOUAUST: "Les Propriétés Magnétiques du Fer aux Fréquences Élevées," *Bulletin de la Société Internationale des Electriciens*, Ser. 3, vol. 1, p. 49, 1911.

‡ L. SCHAMES: *Annales de Physik*, vol. 27, p. 94, 1908.

Since the apparent permeability\* of the iron was small, owing to the screening effect of eddy currents, it was essential that the iron should occupy the largest possible space inside the winding of a test ring, so that the self-induction of the test ring should depend chiefly on the permeability of the iron. The construction of the test rings was such that the iron occupied more than two-thirds of the cross-sectional area of the coils. The effect of the non-ferric portion of the cross-sectional area on the voltage across the terminals of a test ring, with a given current flowing through the winding, was less than 1 per cent, since the voltage due to the non-ferric portion is approximately in quadrature with that due to the iron alone (see Fig. 2). It can be shown that the ratio of the ferric to the non-ferric portion, for a given cross-sectional area of iron, is a maximum when the core, including the insulation

insulate the core, and winding it with silk-covered wire of small diameter, several turns being in parallel.

#### ARRANGEMENT OF CIRCUIT.

Fig. 1 shows the main and shunt circuits of the Poulsen generator. The shunt circuit consists of a Moscicki condenser (0.00212 mfd.), variable inductance, test ring, current transformer, and three variable non-inductive rheostats in parallel. The frequency of the current in the shunt circuit was measured by a Lorenz wavemeter. When making tests at a given frequency, the wavemeter was first adjusted to the desired frequency. To vary the current, the rheostats were altered and the shunt circuit tuned by adjusting the variable inductance until resonance was obtained in the wavemeter circuit. Variations in resistance made little difference in the frequency at

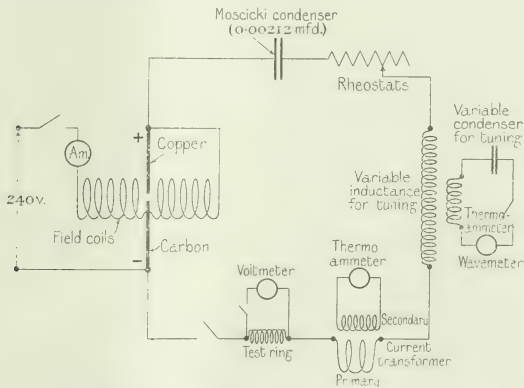


FIG. 1. Arrangement of Poulsen arc generator and wavemeter circuits.

between the discs, is square in section. This condition also gives the minimum length of winding, i.e. minimum perimeter of the core. The cores could not be made square in section, however, because of limitations imposed by the output of the generator. In order to obtain a reasonably large magnetizing force and a wide range of frequency, the weight of iron used had to be reduced; and since the iron used was in the form of plates, it was essential that the ratio of the radial width to the thickness should be large. If the number of plates had been such as to make the iron section square, the weight of iron would have been too large. The resistance of the windings, and the ratio of the area of the non-ferric to the ferric portion, were kept as small as possible, by using fine silk tape to

$2 \times 10^5 \sim$  and  $3 \times 10^5 \sim$ ; but at the higher frequencies the effect was more marked. Provided that the frequency was adjusted to within 2 per cent, the voltage on the terminals of a test ring altered by less than 1 per cent when a constant current was flowing, owing to the variation in  $B_{max} \times f$  at such high frequencies being comparatively small. This holds for the highest frequencies and currents attained; for lower frequencies and currents the error is less, i.e. the adjustment need not be so accurate.

The copper-carbon arc, in series with 4 field coils producing the magnetic blast, was connected across a 240-volt circuit and burnt in an atmosphere of coal-gas. The gas was supplied continuously, an exhaust pipe being employed to discharge the used gas into the atmosphere. The positive electrode was a bar of copper 15 mm. in diameter, and the negative electrode a rod of graphite, also 15 mm. in diameter. Owing to the burning away of the graphite, the length of the arc varied, thereby altering the

\* Apparent Permeability =  $B_{max}/H_{max}$ , where  $B_{max}$  = maximum apparent flux density in the iron, i.e. (total flux through iron)  $\div$  (cross-sectional area of iron), and  $H_{max}$  = maximum apparent magnetizing force calculated from the maximum current through the winding of a test ring.

frequency and current and causing unsteady burning. To eliminate this as far as possible with a hand-operated arc, the end of the negative electrode was carefully ground up and rotated slowly when the arc was burning. A newly ground electrode was inserted for each set of readings.

#### METHODS OF MEASUREMENT.

The current through the shunt circuit was measured by means of a current transformer having a transformation ratio of 3:100, the readings being accurate to within 1 per cent at all frequencies used in the tests. The primary winding consisted of 6 turns of stranded wire and the secondary of 200 turns, the terminals of the latter being connected to a Duddell portable thermo-ammeter having a resistance of 167 ohms.

The voltage across a test ring was measured by a hot-wire instrument with a series resistance of very fine

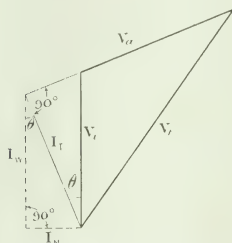


FIG. 2.—Vector diagram illustrating the method of determining the power factor of a test ring, the ohmic pressure-drop and the effect of the non-ferrous portion of the ring being negligible. The current and voltage waves have been assumed to be sinusoidal.

- $V_a$  = volts on test ring due to iron.
- $V_r$  = volts across coil.
- $V_t$  = vector sum of  $V_a$  and  $V_r$ .
- $I_m$  = total current through shunt circuit at 90° to  $V_t$ .
- $I_n$  = energy current in phase with  $V_t$ .
- $I_p$  = magnetizing current at 90° to  $V_t$ .

manganin wire, the current for a full-scale reading being 0.19 ampere. The resistance was wound in such a manner that the inductance and capacity were very small. In order to test the self-induction of the voltmeter, several Moseicki condensers and a variable condenser were put in series with it. The latter condenser was adjusted till the voltmeter reading was a maximum. Under this condition the current through the voltmeter circuit and the voltage across its terminals were in phase. The maximum voltage obtained in this way was not affected appreciably by dielectric and ohmic losses in the remainder of the voltmeter circuit. These losses were negligible since the current and voltage were small. These readings (at  $10^5 \sim$ ) were found to be only 5 per cent larger than the readings obtained with the voltmeter alone. For additional assurance an attempt was made to measure the self-induction by means of a Campbell mutual standard and a Duddell vibration galvanometer. The self-induction was, however, too small to be measured at a frequency of  $500 \sim$ . Allowance was made for the current taken by the vol-

meter by subtracting it from the current in the shunt circuit. This introduced an error of less than 1 per cent, since the power factor of a test ring was never less than 0.8. This correction becomes of more importance at the higher frequencies, since the voltage across a test ring, for a given shunt current, increases with the frequency.

The watts lost in the core of a test ring were found by determining the power factors of the ring for various frequencies and currents, and measuring the current through the winding and the voltage across its terminals. The power factors were obtained by using a slight modification of the well-known 3-voltmeter method of measuring power.

Fig. 3 shows the arrangement of the apparatus diagrammatically. A test ring is connected in series with an auxiliary air-core inductance of very low resistance wound with stranded wire, the number of turns being such that  $V_a$  is approximately equal to  $V_r$ , this giving maximum accuracy. The voltage-drop is measured across (1) the test ring, (2) the auxiliary inductance, (3) the test ring and

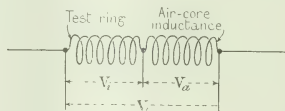


FIG. 3.—Arrangement for determining the power factor of a test ring.

the inductance in series. These three voltages which are assumed to be sinusoidal in wave-form give a triangle, as shown in Fig. 2. Since  $V_a$  is 90° out of phase with the current in the shunt circuit, it is possible, by drawing  $I_m$  as shown in Fig. 2 and setting off its magnitude to scale, to obtain  $I_n$  and  $I_p$ . The power factor is  $\cos \theta$ ,  $\theta$  being the angle between  $V_t$  and  $I_r$ . From Fig. 2, it can be shown that

$$\cos \theta = \frac{V_t}{2 V_r} (4 V_r^2 - V_t^2)^{\frac{1}{2}} \text{ when } V_a = V_r.$$

It can also be shown that an error of 1 per cent in reading  $V_a$  or  $V_t$  (assumed to be equal) involves errors of 1.5 per cent and 3 per cent in the value of  $\cos \theta$ , for 0.25 mm. silicon-iron plates and 0.38 mm. pure iron plates respectively, at  $f = 2 \times 10^5 \sim$ . The errors in all cases decrease as the power factor and frequency increase. In order that the current taken by the measuring instrument should be as small as possible, the voltage was ascertained by using a Duddell thermo-ammeter in series with a fine manganin wire resistance of very small inductance. Since the voltage waves have been assumed to be similar in shape, any inductance in this resistance will affect the three readings proportionately, and will therefore leave the power factor unaffected. Owing to the sluggish action of the thermo-ammeter, steady readings were obtained.

For a given frequency and different values of the maximum apparent magnetizing force  $H_{max}$ , the variation in the power factor was small. In view of this and the errors already mentioned, an average value was chosen for each set of readings.

In order to prevent leakage to earth, the whole of the apparatus in the shunt circuit was mounted on blocks of paraffin wax. Condenser action in connection with the voltmeter was reduced to a minimum by connecting up the circuit in such a way that one terminal of the instrument was at earth potential. At the same time the relative positions of the various pieces of apparatus were such that interaction was negligible.

The method of procedure adopted when taking the readings was to adjust the rheostats to get a certain current, and then tune the circuit to the desired frequency.

- (1) The harmonics of any importance, and the relative magnitudes thereof for various currents (a) without a test ring in the circuit, (b) with a test ring in the circuit;
- (2) The constancy of the wave-form under these conditions.

The first investigation was carried out by employing various wavemeter coils and observing the readings of a Duddell portable thermo-ammeter in the wavemeter circuit, when the latter was tuned to the fundamental or

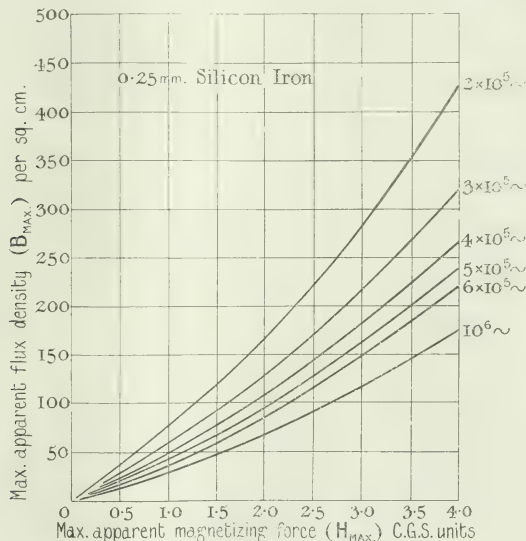


FIG. 4.—Alternating-current B-H curves at various frequencies.

The circuit was then broken until the iron cooled to air temperature, after which the circuit was again closed and readings of the voltage and current taken as quickly as possible. This precaution was very essential for large currents and the higher frequencies, since the apparent permeability, being a function of the specific resistance, increased with rise in temperature, thereby causing an increase in the voltage on a test ring for a given value of the current. In view of this, the small errors at the higher frequencies due to the inductance of the voltmeter resistance were neglected.

#### ANALYSIS OF WAVE-FORM OF SHUNT CURRENT.

The wave-form of the current supplied in the shunt circuit of the generator was investigated by finding:

some harmonic of the current wave in the shunt circuit of the generator. The scales of the wavemeter were such that two coils could be used to read the same frequency. Thus the ratio of the coil constants could be determined experimentally by obtaining the ratio of the thermo-ammeter readings for the same frequency. Hence the ratios of the harmonics to the fundamental were found.

At  $2 \times 10^5 \sim$  the harmonics were very weak, traces being found of the third and fourth. As the frequency increased, the second harmonic became prominent, its R.M.S. value at  $6 \times 10^5 \sim$  being 20 per cent of the fundamental, while the third and other harmonics were practically non-existent. Although this percentage is fairly large, the difference between the form factor of the current wave and that of a sinusoidal current wave is

only 2 per cent, no matter what phase differences the fundamental and the second harmonic may have with regard to each other. Since there is an even harmonic, the positive and negative half-waves are not similar, *i.e.* the current wave is asymmetrical. The second harmonic is very prominent at frequencies above  $3 \times 10^5 \sim$  if the carbon is badly burnt away. In this case the burning is accompanied by a loud hissing noise and the arc wanders

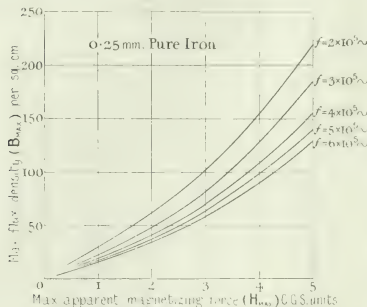


FIG. 5.—Alternating-current B-H curves at various frequencies.

over the face of the carbon and is not confined to the upper edge. The end of the carbon then resembles a spherical segment indented with a series of small sawcuts. Harmonics may be reduced by making the arc length

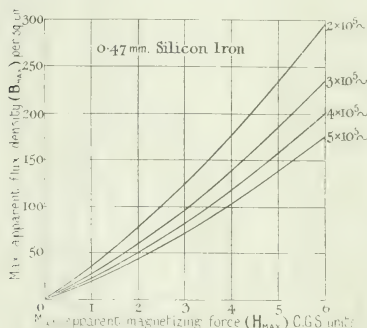


FIG. 6.—Alternating-current B-H curves at various frequencies.

(especially for large currents and the higher frequencies) as small as possible for steady burning. As an example, at  $4 \times 10^5 \sim$  the second harmonic was 34 per cent of the fundamental. By diminishing the length of the arc the ratio was reduced from 34 per cent to 15 per cent, while the current through the arc increased about 30 per cent and the burning was quieter.

The harmonics seem to depend on the ratio of the shunt current to the current through the arc. The smaller this ratio the smaller are the relative values of the harmonics compared with the fundamental. This is probably due to the fact that the smaller the above ratio the more nearly the phenomenon accords with the "Duddell" phenomenon or musical arc. For the capacity used (0.00212 mfd.), the current in the shunt circuit, for any given current through the arc, increases with decrease in inductance. When the ratio of the shunt current to the arc current is large (*i.e.* when the inductance is decreased and the frequency increased), the wave-shape of the former becomes irregular and the second harmonic more prominent.

The effect of one of the test rings in the circuit was to increase the second harmonic slightly at frequencies above  $3 \times 10^5 \sim$ . This was due to a smaller number of turns of the variable air-core inductance being employed at the higher frequencies than at the lower frequencies; hence the inductance of the test ring became of greater relative

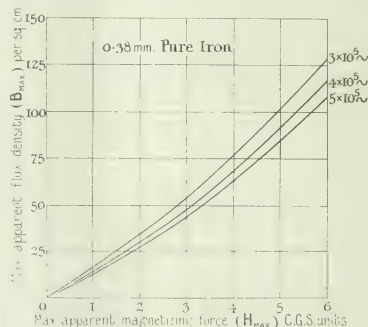


FIG. 7.—Alternating-current B-H curves at various frequencies.

importance. For frequencies lower than  $3 \times 10^5 \sim$ , the effect of the iron was comparatively slight. It was found that the ratios of the harmonics to the fundamental were constant for a given frequency and varying current.

The constancy of the wave-form of the current in the shunt circuit was investigated by measuring the voltage across a solenoid wound with stranded wire in such a manner that the ohmic pressure-drop was negligible. Any alteration in the relative values of the fundamental and harmonics of the current wave would be apparent in the voltage measured across the solenoid. The relationship between the voltage and the current was a linear one for all frequencies, showing that the wave-form was constant. The presence of one of the test rings in circuit had very little effect on the wave-form for a given frequency and varying current. These results corroborate the observations made with the wavemeter.

#### RESULTS OF EXPERIMENTS.

Figs. 4 to 11 show the results obtained. The curves plotted are such that complete data regarding the four cases can be obtained therefrom. The values of  $B_{max}$ , (the

maximum apparent flux density in the iron) were obtained from the formula

$$B_{\max} = \frac{V_{R.M.S.} \times 10^7}{4.44 a f n};$$

The maximum apparent magnetizing force,  $H_{\max}$ , at the skin of a plate, calculated from the shunt current, consists of two components  $90^\circ$  out of phase with each other, namely,  $H_w$ , the energy component balancing the losses,

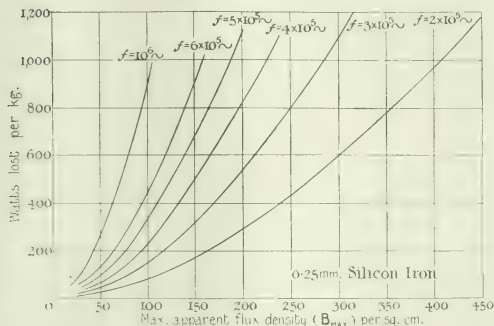


FIG. 8.—Curves showing the relation between the maximum flux density ( $B_{\max}$ ) and the watts lost per kg. ( $W$ ) at various frequencies.

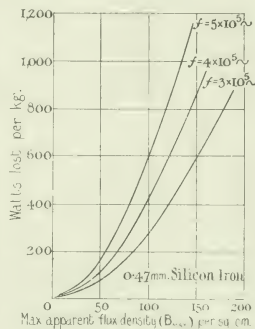


FIG. 9.—Curves showing the relation between the maximum flux density ( $B_{\max}$ ) and the watts lost per kg. ( $W$ ) at various frequencies.

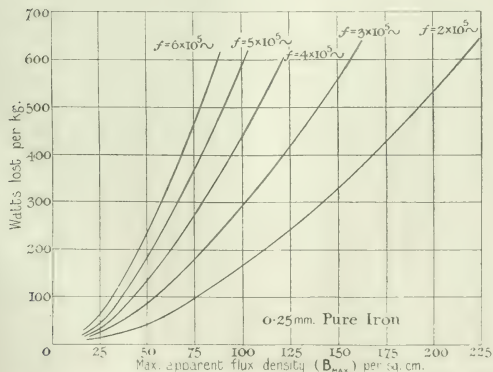


FIG. 10.—Curves showing the relation between the maximum flux density ( $B_{\max}$ ) and the watts lost per kg. ( $W$ ) at various frequencies.

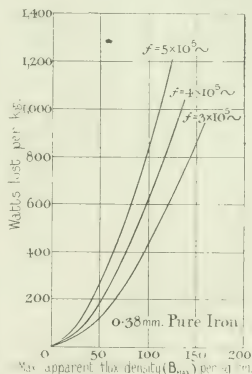


FIG. 11.—Curves showing the relation between the maximum flux density ( $B_{\max}$ ) and the watts lost per kg. ( $W$ ) at various frequencies.

where  $V_{R.M.S.}$  = voltage on the terminals of a test ring,  
 $a$  = cross-sectional area of core,  
 $f$  = frequency in periods per second,  
 and  $n$  = number of series turns on core.

and  $H_w$  the component magnetizing the iron. Owing to the phase differences and varying amplitudes of the magnetizing forces at different depths in the iron, the values of  $H_w$  and  $H_m$ , obtained as shown in Fig. 12, are not the

same as those at low frequencies when the magnetization is uniform throughout the plate.

If one of the plates is considered to be divided up into a very large number of very thin laminae, the angle  $\theta$  for a given apparent magnetizing force at the skin will vary with the depth of the lamina beneath the surface. At the same time the angle for any particular lamina will vary with the apparent magnetizing force at the skin.

The power factor of a test ring obtained by the method already described may be termed the "mean" power factor for a given value of  $H_{\max}$ . Similarly the symbols  $H_w$  and  $H_m$  may be termed the maxima mean values of the energy and magnetizing components of  $H_{\max}$ .



FIG. 12.—Vector diagram showing the relation between  $H_{\max}$ ,  $H_w$ , and  $H_m$ .

$H_{\max}$  = max. appar. magnetizing force at skin of plate;  
 $H_w$  = max. mean energy component  
 $H_m$  = max. mean magnetizing component.  
 $\cos \theta$  = mean power factor of test ring (see Fig. 2).

Figs. 4 to 7 show, for various frequencies, the relation between the maximum apparent flux density  $B_{\max}$ , and the maximum apparent magnetizing force  $H_{\max}$ . It will be observed that with both silicon iron and pure iron the curves are different in shape from the ordinary B-H curves for the same range of values of the magnetizing force. These curves, however, are of the same shape as those obtained by Alexanderson at lower frequencies.

#### EFFECT OF FREQUENCY.

It will be observed from Figs. 4 to 7 that, as the frequency increases, the B-H curves come closer together. The diminution in  $B_{\max}$  for a given value of  $H_{\max}$  is not inversely proportional to the frequency, but inversely proportional to some power of the frequency less than unity. Alexanderson<sup>2</sup> found that for 0.08 mm. plates of pure iron the voltage per turn per square centimetre of iron in the core, for a given value of the magnetizing force, increases with the frequency, the curve showing the relation between the two being similar in form to a B-H curve under static magnetization. The relation was almost linear for frequencies greater than 60,000  $\sim$  and  $H_{\max} = 5.3$ . In the present instance the plates were thicker than 0.08 mm. and the frequency at which the relationship became almost linear, i.e. where the curve bent over, would not be expected to occur at 60,000  $\sim$ . However, the relationship for silicon iron from  $2 \times 10^5 \sim$  to  $10^6 \sim$  was practically linear, while that for pure iron from  $2 \times 10^5 \sim$  to  $6 \times 10^5 \sim$  was of the same nature.

For a given value of  $B_{\max}$ , the watts lost per kilogram increase with the frequency. The relation between the watts lost per kilogram and the frequency for a given value of  $B_{\max}$  may be written  $W = cf^n$ , where  $n$  is an index which decreases with increase in frequency and flux density, having an average value of 1.55 for 0.25 mm. plates of silicon iron when  $B_{\max} = 100$  and  $f = 2 \times 10^5 \sim$  to  $6 \times 10^5 \sim$ . For pure iron plates of the same thickness (0.25 mm.) the index is smaller.

By plotting watts lost per kilogram against the frequency, for a given number of volts per turn per square centimetre of cross-section of iron, Alexanderson obtained a curve like a rectangular hyperbola, which showed that, other things being equal, it is more efficient to use iron at high than at low frequencies. The author's experiments show that this is true for frequencies from  $2 \times 10^4 \sim$  to  $10^6 \sim$  for silicon iron, and for frequencies from  $2 \times 10^5 \sim$  to  $6 \times 10^5 \sim$  for pure iron. At these frequencies the relation between watts lost per kilogram and frequency is nearly a linear one.

The equivalent depth of uniform magnetization, on the assumptions that there is no hysteresis and that the permeability is constant,<sup>3</sup> is given by:—

$$d = \frac{1}{2\pi} \left( \frac{\rho}{2\mu f} \right)^{\frac{1}{2}}$$

where  $\rho$  = specific resistance of material in C.G.S. units,

$\mu$  = permeability (assumed constant),

and  $f$  = frequency (periods per second).

In compiling Table 1, the specific resistances of silicon iron and pure iron have been taken as 12.5 and 54.5 microhms per cm. cube respectively, and the permeability has been assumed to be 2,500.

The experimental results in Table 1 were obtained as follows. The value of  $H_m$ , the magnetizing component of the current through the winding of a test ring, was calculated from the corresponding values of  $H_{\max}$  and the power factor (see Fig. 12). The value of  $B$ , corresponding to this value of  $H_m$  was found from a static B-H curve.

Then  $d = a B_{\max}/B_p$ , where  $B_{\max}$  = maximum apparent flux density due to alternating magnetizing force  $H_{\max}$ ;

$B_p$  = flux density due to static magnetizing force  $H_m$ ;

and  $a$  = semi-thickness of plate.

It is probable that the discrepancy between the experimental and calculated results is due to the assumptions made in deriving the formula. From Table 1 it will be seen that the frequency affects the calculated and experimental equivalent depths in almost the same proportion, showing that the equivalent depth varies inversely as the square root of the frequency. It is quite conceivable, owing to the phase differences and varying amplitudes of the magnetizing forces, and to the variation in permeability at different depths in the iron, that the actual depth to which the magnetism penetrates is greater than that indicated by the figures in Table 1.

A series of figures is given in Table 4, showing the effect of the frequency on the power factor. The alteration

<sup>3</sup> A. RUSSELL: "The Theory of Alternating Currents," 2nd Edition, vol. 1, p. 499

<sup>\*</sup> Loc. cit.

therein from  $2 \times 10^5 \sim$  to  $5 \times 10^5 \sim$  is slight. At these frequencies, the thickness of the plates used in the experiments is large compared with the equivalent depth of uniform magnetization, while at a frequency of  $50 \sim$  the

TABLE 1.

$H_{\max.} = 4$  C.G.S. units.

Material	Equivalent Depth of Uniform Magnetization		Frequency
	Calculated	Experimental	
	mm.	mm.	$\sim$
0.25 mm. silicon iron	0.011	0.0075	$2 \times 10^5$
" " "	0.0072	0.0045	$5 \times 10^5$
0.25 mm. pure iron ...	0.0054	0.0025	$2 \times 10^7$
" " "	0.0035	0.0017	$5 \times 10^5$

thickness is comparatively small. Hence, from this point of view, the power factor could only be expected to undergo changes of small magnitude.

#### EFFECT OF SPECIFIC RESISTANCE.

In Table 2 a series of figures is given illustrating the increase in  $B_{\max.}$  caused by an increase in the specific

TABLE 2.

$f = 3 \times 10^5 \sim$ . Ratio of Specific Resistances = 4:1.

Material	$H_{\max.}$ (apparent)	$B_{\max.}$ (apparent) per sq. cm.	Ratio of Flux Densities
0.25 mm. silicon iron	2	126	2.57
" pure "	2	40	
" silicon "	4	320	2.50
" pure "	4	128	

TABLE 3.

$f = 3 \times 10^5 \sim$ .

Material	$B_{\max.}$ (apparent) per sq. cm.	Watt Lost per kg.	Ratio of Watts Lost per kg.
0.25 mm. silicon iron	100	155	1.88
" pure "	100	292	
" silicon "	150	322	1.75
" pure "	150	562	

resistance of the iron for constant apparent magnetizing forces of 2 and 4 C.G.S. units respectively. The ratio of the flux densities in silicon iron and pure iron is about 2.5,

and is sensibly constant for 0.25 mm. plates when the frequency varies from  $2 \times 10^5 \sim$  to  $6 \times 10^5 \sim$  and  $H_{\max.}$  from 1 to 4 C.G.S. units.

TABLE 4.

Material	Frequency $\sim$	Average of Mean Power Factor of Test Ring	Ratio of Power Factors
0.25 mm. silicon iron	$2 \times 10^5$	0.90	1.07
" pure "	"	0.84	
" silicon "	$5 \times 10^5$	0.92	1.07
" pure "	"	0.86	

The equivalent depth of uniform magnetization is affected by specific resistance as shown in Table 1 above, the values for silicon iron being about three times those for pure iron, the apparent magnetizing force being the same in both cases. This shows that the equivalent depth does not vary as the square root of the specific resistance, as predicted by theory on the assumption of constant permeability. The difference between the calculated and experimental results is more marked with pure iron than with silicon iron.

For given values of  $B_{\max.}$  and frequency, an increase in the specific resistance causes a diminution in the watts lost per kilogram. The ratio of the losses with pure iron to those with silicon iron, at a given frequency, decreases as  $B_{\max.}$  increases. For a given value of  $B_{\max.}$ , the ratio decreases with increase in frequency. It follows, therefore, that the advantage of silicon iron compared with pure iron becomes less as the flux density and frequency increase.

For plates of the same thickness and a given value of  $H_{\max.}$ , the value of  $B_{\max.}$  is greater for silicon iron than for pure iron, and the watts lost per kilogram are greater for silicon iron than for pure iron.

The data in Table 4 show that the mean power factor of a test ring having a core of silicon iron is larger than that of one with a core of pure iron, in spite of the fact that for given values of  $B_{\max.}$  and thickness of plate, the losses in the latter material exceed those in the former.

#### EFFECT OF THICKNESS.

For given values of  $H_{\max.}$  and frequency, the total flux through a plate does not increase with the thickness; it actually diminishes, i.e. the surface laminæ of a thick plate are not so effective as a medium for carrying flux as the surface laminæ of a thin plate (see Table 5). This is probably due to the fact that at a certain depth below the surface the flux is opposite in phase to the flux at the surface, and that consequently the resultant flux through the plate is diminished.

With silicon iron the ratio of the apparent flux densities for different thicknesses decreases with decrease in  $H_{\max.}$  and for a given value of  $H_{\max.}$  there is little variation with change in frequency.

With pure iron the ratio for a given frequency decreases with decrease in  $H_{\max.}$ , being 1.47 when  $H_{\max.} = 2$  and

$f = 3 \times 10^5 \sim$ , as against 1.66 shown in Table 5 when  $H_{\max} = 4$ . The effect of change in frequency is more marked with pure iron than with silicon iron, the ratio of the flux densities decreasing with increasing frequency, being 1.57 (for pure iron) when  $H_{\max} = 4$  and  $f = 5 \times 10^5 \sim$ . The total flux through plates of different thicknesses as given in Table 5, at a frequency of  $5 \times 10^5 \sim$  and  $H_{\max} = 4$ , is therefore nearly the same, i.e. the equivalent depth of uniform magnetization is the same.

TABLE 5.

$$f = 3 \times 10^5 \sim.$$

Material	$H_{\max}$ , (apparent) G.O.S. Units	$B_{\max}$ (apparent) per sq. cm.	Ratio of Flux Densities	Flux per Plate for Equal Ratio Wattles	Ratio of Thick- nesses
0.25 mm. silicon iron	4	320	2.32	51	1.88
0.47 mm. " "	4	138		41	
0.25 mm. pure "	4	128	1.66	21	1.52
0.38 mm. " "	4	77		10	

TABLE 6.

$$f = 3 \times 10^5 \sim.$$

Material	$B_{\max}$ , (apparent)	Watts per kg.	Ratio of Losses	Ratio of Thicknesses
0.25 mm. silicon iron	100	155	1.79	1.88
0.47 mm. " "	100	278		
0.25 mm. pure "	100	202	1.47	1.52
0.38 mm. " "	100	430		

TABLE 7.

Material	Frequency $\sim$	Average of Mean Power Factor of Test Ring
0.25 mm. silicon iron ...	$2 \times 10^5$	0.90
0.47 mm. " " ...	"	0.88
0.25 mm. pure " ...	"	0.84
0.38 mm. " " ...	"	0.8

At low frequencies the eddy-current loss increases in proportion to the square of the thickness of the plates, but at these frequencies the losses\* do not increase in proportion even to the thickness of the plates (see Table 6).

\* At such high frequencies the losses are chiefly due to eddy currents.

The reason for this is quite clear from a consideration of skin effect, the only active part of the material being the surface laminae. With both silicon iron and pure iron the ratio of the losses in plates of different thicknesses, as given in Table 6, is constant for frequencies between  $3 \times 10^5 \sim$  and  $5 \times 10^5 \sim$ , the value of  $B_{\max}$  being the same in both cases. An increase in  $B_{\max}$  between these frequencies causes an increase in the ratio of the losses. It follows, therefore, that the advantage of using thin plates becomes smaller as the flux density increases.

Owing to the complex conditions within the iron, it is difficult to ascertain from theoretical considerations in what way the power factor should vary with the thickness. For the thicknesses of plate used, the power factor increases with decrease in thickness.

If an exceedingly thin plate, in which the flux density is uniform, be considered, the eddy-current loss will be comparatively small. The energy current will be a smaller proportion of the apparent magnetizing current, and the power factor will therefore be smaller than that for the thicknesses used in these tests.

Alexanderson has shown for 0.08 mm. plates of pure iron at  $2 \times 10^5 \sim$  that the power factor of a coil with this material as a core is 0.8. The author obtained the same value for 0.38 mm. plates of pure iron, but a larger value for 0.25 mm. plates of the same material. This seems to show that at a given frequency there is a thickness of plate for which the power factor is a maximum.

TABLE 8.

$$f = 3 \times 10^5 \sim. \quad H_{\max} = 4.$$

Material	Equivalent Depth of Uniform Magnetization	
	Calculated	Experimental
0.25 mm. silicon iron ...	0.0093 mm	0.0058 mm
0.47 mm. " " ...	0.0093	0.005
0.25 mm. pure " ...	0.0045	0.0021
0.38 mm. " " ...	0.0045	0.0018

It is evident from Table 8 that the equivalent depth of uniform magnetization increases with decrease in thickness for both silicon iron and pure iron, this being in agreement with the results given in Table 5. The discrepancy between the calculated and experimental results may again be accounted for by the variation in the permeability throughout the thickness of the plate.

In conclusion, the author wishes to convey his best thanks to Professor E. W. Marchant, D.Sc., for his criticisms and the interest he has taken in the work. He also desires to thank Messrs. Joseph Sankey and Sons for providing the material tested.

# NOTES ON SOME SMALL POINTS RELATING TO DUPLEX BALANCES ON LONG SUBMARINE CABLES.

By WALTER JUDD, Member.

(Paper received 23 February, 1916.)

The following notes are the result of observations made by Mr. W. Gaye in the Laboratory of the Eastern Telegraph Company, and are communicated as being of interest to others charged with the maintenance of duplex balances on long submarine cables.

Various phenomena lead to the deduction that even the relatively small capacity of the connecting wires con-

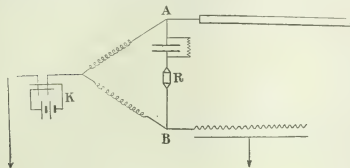


FIG. 1.

cerned in a cable duplex system—such wires being generally of considerable length—enters into the problem of duplex balancing to an appreciable extent. Manifestations of these phenomena are:—

(1) A balance which has been observed to be good on one siphon recorder is often found to need more or less small re-adjustment when the circuit is transferred to

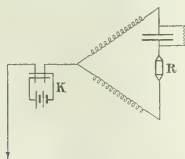


FIG. 2.

another recorder or to a relay, the only difference being that another pair of connecting wires is used for the second piece of apparatus.

(2) If both the cable and artificial line are disconnected from the system a small balance disturbance is invariably shown.

(3) On what are known as oscillatory curb connections such as those shown in Fig. 1, if large changes are made in the capacity of the condenser or the resistance of the shunt over it, a previously existing good balance may be somewhat upset.

(4) When the entire cross circuit is short-circuited by connecting a wire of negligible resistance between the points A and B (Fig. 1), a disturbance of a good balance may be produced.

These curious effects are likely to be attributed to defective insulation existing at some point of the system, but they are found to occur when all the apparatus and leads are known to be well insulated.

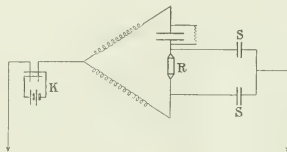


FIG. 3.

In order to account for their occurrence it becomes necessary to dismiss from consideration the cable and artificial line and to study the connecting wires alone. If this be done and the circuit becomes of the simple character shown in Fig. 2, it is clear that application of the battery electromotive force to the bridge apex by depression of one of the signalling keys (K) will have no result, since

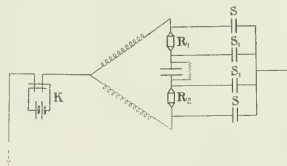


FIG. 4.

both sides of the observing instrument (R) instantaneously acquire and maintain the same potential.

If, however, the two connecting wires on either side of R have each a capacity S to earth, then we may represent the conditions as in Fig. 3. Here a manifestly unsymmetrical condition is displayed, and it is evident that the application of the electromotive force will have a transient disturbing effect upon R, greater or less according to the capacity, S, of the leads.

We are, in fact, confronted with a condition of things that calls for remedy before the main problem of balancing

the artificial line against the cable is attacked. It seems reasonable to suppose that, unless this be done, the elimination of these entirely local effects may considerably aggravate any other difficulty that may be experienced.

We shall be well advised therefore to discuss what expedients can be adopted to remedy an obviously undesirable lack of symmetry. Those which suggest themselves are:—

(1) To make the connecting wire between the receiving instrument R and the condenser as short as possible, so that the latter becomes, as it were, part and parcel of the former. The objection to this is that the condenser on even moderately long cables may under ordinary circumstances become a very bulky piece of apparatus occupying a prohibitively large space.

(2) To use connecting wire having a thickness of insulation so great as to make its capacity per unit length negligible.

(3) To divide the condenser into two equal parts and to place one on each side of R. This would involve four times the capacity of the original condensers and would be objectionable on the score of cost.

(4) To adopt the Price wire-guard principle in regard to these wires. That is to say, to connect the screen surrounding the wire to the bridge apex and thus nullify the capacity.

(5) To divide the coil of R into exactly equal parts, R<sub>1</sub> and R<sub>2</sub>, and to insert the condenser between these two parts as shown in Fig. 4. This provides a symmetrical arrangement at no greater cost than that of two similar additional lengths of connecting wire, the capacity of which is represented by S<sub>1</sub>.

The diagrams given show the connections where a magnetic bridge duplex system is in use, but the argument applies equally well to cases where a simple resistance bridge or a double block condenser bridge are employed.

## DISCUSSION ON

### "THE DESIGN OF HIGH-PRESSURE DISTRIBUTION SYSTEMS."

#### FURTHER CONTRIBUTION TO THE DISCUSSION.

Mr. Price.

Mr. B. PRICE (*communicated*): This paper is of special interest to me because I shared in the earlier development of the large and successful system on the North-East Coast to which the author makes more than a casual reference. Twelve years ago, when that system was in its infancy, the principles so clearly stated in the opening paragraphs of the paper had already been fully grasped, and the idea of a vast interconnected high-tension system, such as that shown in Fig. 8, was already prominently in mind. The arguments in favour of such a development were specially strong in that particular district because, in addition to the necessity for meeting the power requirements of scattered collieries and other consumers, it was of immense importance that the waste heat from coking plants and the waste steam from blast-furnace blowing engines should be utilized for the generation of cheap electric power. These sources of cheap power could not be tapped unless the high-tension system of the power companies was extended to reach them, and it became clear, therefore, that the system must be suitable for extension over a very wide area and must be designed with a view to reaching any point within that area. Whilst, in many directions, the development of the art had made adequate progress, the way was not yet clear in every respect. The advent of steam turbine-driven generating plant had removed all difficulty in regard to the satisfactory parallel running of widely separated stations, and had rendered possible a large increase in the size and economy of generating units. Mains, switchgear, and transformers had been developed

well up to requirements, although experience with the latest types was somewhat limited. The novel features of the problem from the engineering standpoint lay more in the direction of the regulation and control of such extended networks, and for a time this aspect appeared to constitute a real difficulty. It was the application of the differential principle to the design of automatic protective devices which removed these difficulties and rendered it possible to design the lay-out of such a system at minimum capital cost.

*Lay-out of systems.*—The author has investigated the cost of certain typical lay-outs (see Fig. 9) in order to prove that the chessboard type involves minimum capital expenditure, but I believe that even without such proof the type of lay-out shown in Fig. 8 will be accepted by power-scheme engineers as the cheapest, safest, and most convenient that could be devised. Not only is each point of supply fed over widely divergent routes from the maximum number of sources of supply, but the mains are spread more or less uniformly over the area and are therefore in the best position for feeding future consumers. Inasmuch as the cost of a high-tension underground cable is much more than the cost of excavating the trench in which it is to be laid, and as the cost of copper and insulators is the major item in the cost of an overhead line, it must be wrong, as a general principle, to run more than one circuit along each individual route, though this may be advisable under exceptional circumstances. It should be specially emphasized that a system of this type could not be operated to meet commercial requirements

\* Paper by Mr. J. R. Beard (see pp. 125, 225, 291, 379, and 431).

were it not for the discriminating properties of the automatic protective gear with which it has been equipped. Since 1909 I have been able to study the operating characteristics of the extensive power scheme on the Rand in South Africa, where conditions differ materially from those obtaining on the North-East Coast of England, and it may be of interest to mention some of the conclusions which may be drawn from the experience gained, as bearing on the matters dealt with in the paper. The Rand is a very narrow strip of country, about 50 miles long, situated on a plateau at an altitude of close upon 6,000 ft. above sea-level. It is particularly prone to severe lightning storms, accompanied in many instances by tornadoes of wind, hail, and rain. Large birds of the hawk tribe are common, and some of these exhibit a peculiar preference for the use of metal wire in the building of their nests, the sites for the latter being frequently chosen in the uppermost section of the lattice-work of steel transmission towers. It is probable that there are few localities in the world which offer more severe conditions for overhead working, and as the whole of the main transmission system and the major portion of the high-tension distribution system have been constructed overhead, ample experience has been gained. The system comprises well over 200,000 k.v.a. of generating plant installed in four generating stations feeding 136 miles of 80,000-volt, 82 miles of 40,000-volt, 66 miles of 20,000-volt, and 63 miles of 10,000-volt overhead 3-phase circuit, 50 miles of underground 20,000-volt cable, and about 75 static transformer sub-stations ranging in capacity up to over 10,000 k.v.a. per sub-station. Under these conditions the number of faults occurring on the overhead system has been very many times that of the faults on the underground 20,000-volt cables; in fact, whilst the cables never fail from internal causes, and hardly ever from external causes, the lines fail quite frequently during the six months of the lightning season. The problem of maintaining satisfactory supply to the gold-mining industry under these conditions has been satisfactorily solved by adopting the same principles of design as those which proved so successful on the North-East Coast of England. At the outset, when the system consisted largely of lines and sub-station equipments of antiquated and poor design and before any reliable system of automatic control had been adopted, the damage produced by lightning was appalling, and, at first acquaintance, almost persuaded me to embark upon an extensive experiment under practical working conditions with numerous types of lightning protective gear. It soon became apparent, however, that the system was not being given a fair chance and that the first step should be to improve the automatic control. Whilst interference with the telephone circuits both of the power company and of the Government rendered it impossible to earth the neutral in the ordinary manner at the step-up transformers at generating stations, the use of special step-down transformers having star primaries and delta secondaries removed this difficulty, and the installation of differential protective gear (often termed balanced protective gear) with pilot wires secured the almost instantaneous isolation of all faults. The system was extending rapidly, and this enabled various networks to be converted into a collection of ring mains, thus providing divergent routes for the duplicate feed to each point of supply. A system of

automatic alarms was also provided capable of notifying Mr. Price the headquarters for the district concerned immediately a switch opens at any static sub-station. These alarms are so designed as to indicate to the engineer at headquarters the sub-station at which a switch or switches have opened. He then proceeds by motor-cycle to investigate conditions at such sub-stations. These measures have revolutionized the performance of the system, and the experience of the last few years has proved conclusively that satisfactory supply can be maintained, even under the exceptionally severe conditions obtaining on the Rand, without resort to any more drastic precautions than those mentioned. My conclusions in this connection may be summarized as follows:—

(1) Under such conditions the earthing of the neutral is essential. It enables instantaneously-acting discriminating cut-outs to be used, and it also provides a ready means for inserting a resistance in the path of the current flowing to all but exceptional faults. Experience shows that a fault between phases is relatively infrequent because, as a rule, the initial effect of the induction from lightning is to cause a flash-over on one insulator, and the differential protective gear is sufficiently rapid in its operation to prevent the arc at the insulator from spreading to other phases in all but exceptional cases. Faults between phases are generally the result of a wire thrown wilfully across the lines, or of material such as corrugated iron roofing being blown on to the conductors. The earthed neutral also enables the lightning arresters to operate more satisfactorily. If the neutral is insulated, a fault on one phase increases the pressure on the other two, causing the arresters on these latter to discharge continuously until a second fault to earth develops. The resistance in series with the horn gaps have, of necessity, to be so proportioned as to limit the current to a value which is insufficient to operate the cut-outs, otherwise every arrester discharge would isolate the circuit. The arresters, therefore, continue to discharge until something gives way, and as a rule the arc at the horn gaps spreads to neighbouring ironwork. This continual discharge of the arresters takes place in static sub-stations and is not therefore under the observation of attendants. When the after-effects are examined, the first impression gained is that the lightning has performed extraordinary feats in bridging an air-gap far larger than that between the horns; whereas, in actual fact, the damage has been the final result of prolonged and continuous arrester discharge. The earthing of the neutral entirely removes this difficulty, as it converts every flash-over into a definite fault which the cut-outs are able to isolate and relieves the arresters from unfair duty. Experience with and without an earthed neutral has also provided abundant proof that an insulated system is subjected to very much more severe potential strain at times of high-frequency surge. If by chance the neutral of a section of the overhead system should become insulated during a lightning storm, several flash-overs invariably take place between live conductors and neighbouring ironwork inside buildings at the terminals of the lines. If the neutral is earthed, a flash-over inside buildings may occasionally occur due to a severe flash of lightning striking the line conductors direct or going to earth in close proximity thereto and within a short distance of the end of the line, but this is of rare occurrence.

Mr. Price.

(2) The separation of the routes for supply to any given point on the network prevents the simultaneous failure of such routes in all but exceptional cases.

(3) The use of differential protective gear is essential not only to obtain perfect discrimination (*i.e.* the isolation of the faulty generator, line, or transformer, and of that faulty piece of apparatus alone), but to secure as nearly as possible instantaneous isolation. Although it is impossible to construct a switch which will break the circuit absolutely instantaneously, a switch of good type will complete its stroke within a small fraction of a second, and experience shows that if the relay has no time element, the power arc formed across a line insulator is extinguished before it has had time permanently to damage the porcelain in the majority of cases. If even a small time-element is introduced, every line flash-over will result in a damaged insulator, whereas the use of instantaneously-acting relays enables the line to be at once switched back into service five times out of six. It is partly on this account that divergent routes are efficacious in maintaining uninterrupted supply, because a line which has tripped out due to insulator flash-over is often in service again before the duplicate route is subjected to the influence of the passing lightning storm. On several occasions it has been proved that a network about 6 miles in diameter, comprising a ring main with two radial feeders subdividing it into three adjacent rings, has experienced as many as six separate faults during a severe storm (one or possibly two of which faults have proved to result in a fractured insulator) without causing any interruption to supply. The value of the discriminating properties of differential protective gear can only be fully appreciated by actual experience with and without its aid on a large and complex system under severe operating conditions. In my opinion such gear will in one or other of its various forms become universally adopted for the automatic isolation of all apparatus, including generators, transformers, and feeders. All such plant has been so equipped throughout the system on the Rand, and it would be difficult to overstate the benefits which have resulted. The application of such gear to transformers is now recognized as standard practice, but some engineers appear to be diffident with regard to its use for the protection of generators. On the Rand system, each generator is directly connected to its own step-up transformer, and the combination is then protected by differential relays which actuate the main high-tension switch. This switch in turn operates a switch in the exciting circuit of the generator, so that in the event of failure of the generator or the transformer or any of the connections between the same, the machine is immediately isolated from the system and demagnetized. This arrangement minimizes the damage caused by the fault. In my opinion the two outstanding characteristics of differential protective gear, namely, (a) its instantaneous action, (b) its perfect discriminating properties which are entirely unaffected by the highest overload, render it particularly suitable for application to generating plant. As a rule each generating set has a capacity several times as great as that of any individual line or sub-station transformer, and it is therefore important to ensure that the set will not be automatically isolated from service under any circumstances other than that of its own failure. It is also of advantage that in the event of failure the extent of the damage should

be restricted as much as possible because the time and the cost of repairs is a relatively important matter. Moreover, it must be borne in mind that such sets are in charge of an attendant who is in a position to isolate the machine by hand should any trouble arise other than an internal failure of the generator itself.

(4) Lightning protective gear is probably beneficial, but proof is difficult and it is better to spend money to obtain an increased factor of safety for the apparatus to be protected than to multiply arresters unduly. One thing is certain, namely, that the intensity of the induced effect of lightning is localized to a relatively short length of line in the immediate vicinity of the lightning flash. To prevent entirely insulator flash-overs on the lines, it would therefore be necessary to distribute lightning protective gear of efficient type at frequent intervals throughout the length of all lines, and even then it is by no means certain that any known form of arrester would prove completely effective when so used. My opinion is that the best compromise is to erect earthed wires over the power lines (as has been done throughout the system on the Rand) and to equip the ends of the lines at generating stations and at sub-stations with arrester gear. The earthed wires probably minimize the risk of a lightning flash entering the conductors direct, and they certainly assist to damp out the intensity of the high-frequency surge as it passes along the line. Ordinary horn-gap arresters in series with resistance have been adopted on the Rand, but whether the relative immunity of sub-station apparatus from failure is due to the protection afforded by such arresters is unknown. When given adequate attention, these arresters appear to operate satisfactorily, and presumably they do good rather than harm, but whether or not they relieve the station apparatus from strain, they can be of little if any benefit as a means of protection against faults on the line insulators. I consider, therefore, that line faults in considerable number are and must remain inherent to such a system, and that the design and lay-out of the system must be directed towards enabling these faults to be automatically isolated without interruption to supply. The cost of repairs is a negligible quantity.

(5) A complete and thoroughly reliable telephone and alarm system is essential. For this purpose I would recommend the combination of an ample number of telephone wires and pilot wires in a single lead-covered cable suspended from poles placed at a sufficient distance from the power lines to prevent dangerous induction from the heavy currents flowing through the latter at times of fault. With the growth in size and complexity of modern power schemes, involving, as it does, an ever-increasing number of static sub-stations, I believe it will become standard practice to provide a limited number of pilot wires along all the main distribution routes whether the cut-outs be fitted with differential relays or not. Such pilot wires will be found most useful for any or all of the following purposes:—

- (a) For use with differential relays.
- (b) For operating switch-tripping alarms at district headquarters.
- (c) For enabling certain important switches (for example, at sectionalizing points on the various networks) to be remote-controlled from headquarters. This may

be desirable at times of emergency to avoid overloading certain feeders or to hasten the resumption of supply. It may be equally desirable in everyday routine to ensure maximum safety during lightning storms, whilst at the same time reducing losses of distribution and transformation to a minimum under varying conditions of loading.

- (d) For enabling data to be collected with regard to the performance of the system at times of trouble. Automatic apparatus recently developed in America designed to record the precise time of occurrence of a sequence of events (such as switch operations, lightning flashes, arrester discharges, and fault currents flowing through the neutral earth connections) can then be effectively used.
- (e) For enabling the official in charge of the loading, regulation, and control of the entire system (generally known in America as the "load despatcher," but perhaps better termed the "control engineer" or "system engineer") to obtain direct information regarding the voltage and frequency of various sections of the system by means of instruments placed in front of him in his office.
- (f) Generally, for co-ordinating data from various points on the system to a central point. A special instance of this kind arose on the Rand when it became essential to measure the aggregate of simultaneous maximum demands of a number of widely separated consumers. Whilst carefully adjusted clocks controlling demand attachments on consumers' integrating watt-hour meters might have sufficed, a source of contention was eliminated by controlling all such attachments from one central point.

Without wishing to detract from the merits of the split-conductor system, which undoubtedly is advantageous under certain circumstances, I believe that in many, if not in the majority of cases, it will be found that the differential system involving the use of pilot wires is to be preferred. If telephone wires and pilot wires are required for other purposes, the additional pilot wires for the differential relays can be embodied in the same cable at negligible expense. The duplication of overhead conductors, rendered necessary by the split-conductor system, is in my opinion a complication that should be avoided, and, as explained later, the fact that the split-conductor system can be designed to operate with a very small fault current is of no practical value. The differential system with pilot wires is already more sensitive than is really necessary.

**Switchgear.**—It is unfortunately the fact that the system on the Rand, handicapped as it is by the severity of climatic conditions, was equipped with switchgear of Continental design which proved incompetent for dealing with the many short-circuits occurring in practice. The switches installed for 40,000, 20,000, and 10,000-volt working, though of liberal dimensions and relatively high cost, were designed with insufficient experience of the conditions which can exist on a system of the type in question, *i.e.* one laid out for generating and delivering very large quantities of power over a relatively compact area. With the object of avoiding an excessive number of

circuits and switchgear panels, the voltages chosen have been relatively high in relation to the average distance of distribution. Under such conditions, the rush of power at times of short-circuit between phases is very great and all apparatus in the main circuit is subjected to very severe strain. The type of switch installed proved lamentably deficient when called upon to interrupt these very large quantities of power. It was merely an enlarged reproduction of the earlier switches which had proved effective on smaller systems working at lower pressures. The length and speed of break were inadequate, and no attempt had been made to cool the gases formed at the arc or, in other words, to increase the length of the path for such gases before they reach the air above the oil. In consequence of these defects, serious gaseous explosions were experienced, followed in some cases by oil fires such as few if any other schemes have encountered. In those instances where the gases formed by the disintegration of the oil exploded with the air inside the top of the switch case, the tank was blown down and the oil was generally left ignited. If it happened that the air in the switch was expelled through the vent pipe without explosion, the gases were in exceptional cases exploded with the air outside the switch, bursting the iron doors of the switch chambers and bulging the masonry work. One of the difficulties in dealing with lightning and switch troubles is the impossibility of investigating the phenomena by special tests. All that can be done is to analyse evidence obtained in commercial service and to test the conclusions drawn therefrom by the tedious process of analysing further commercial experience, much of which may be inconclusive. Experience with oil switches on the Rand has led to the following steps being taken:—

- (1) In the case of 40,000-volt switches controlling the main arteries of the system, "explosion pots" have been fitted, *i.e.* insulated cylindrical metal chambers have been so fixed as to surround the immovable contact, and the stroke of the movable contact has been increased sufficiently to allow such contact to move well clear of the bottom of such chamber. It is not claimed that enclosure of the arc within such a chamber assists the oil to quench the arc. The object in view has been to direct the hot gases downwards into the oil instead of allowing them to force a path straight up to the surface. Incidentally, such chambers also relieve the oil tank from the mechanical forces produced by the sudden and violent generation of gas at the arc. The provision of these so-called explosion pots has proved very effective in so far as the prevention of gaseous explosion is concerned.

- (2) In the case of 20,000-volt and 10,000-volt switches controlling the outgoing feeders from generating stations, the length of break has been doubled. Whilst it is as yet too soon to say that this alteration will be fully effective, there is no doubt that it has greatly improved the performance of these switches.

In addition to the above-mentioned alterations, the following steps have also been considered and may subsequently have to be adopted in whole or in part:—

- (1) To double the number of breaks. This would be difficult and relatively expensive in the case of the smaller switches.

- (2) To baffle the path for gases en route from the arc to the surface of the oil. It is not easy to do this effectively

Mr. Price. without incurring expenditure as great as that required for the installation of explosion pots.

(3) To exclude all air from the internal portions of the switch and to fit suitably-designed air-buffer chambers for relieving the mechanical strain produced by the generation of gases at the arc. This again would be a relatively expensive alteration.

(4) To insulate all live conductors in switch chambers.

As switch troubles only occur under the severest conditions, acquisition of experience is a very slow process. Adverse performance is generally conclusive, but experience in favour of an alteration may be inconclusive for a very long time. Having removed the more serious dangers, it is now necessary to wait patiently for proof of the extent to which a cure has been effected. I am dubious with regard to the efficacy of the suggestion cited by the author, to increase the length of break by magnetic repulsion of the currents at the arc. Whilst it is true that the gases have negligible mass, relatively heavy oil must be displaced if the path of the current is to take its place. On a 50-cycle system the current is ebbing and flowing 100 times per second, and the problem is to introduce resistance in the path of the arc at a more rapid rate than that at which the resistance of the path is being reduced by carbonization. The magnetic forces being due to the current, they exist only whilst oil is being carbonized, and it is therefore difficult to see how such forces can assist the introduction of non-carbonized oil into the path at the moment when the current is zero and the voltage is endeavouring to restart it. It would seem that there are only two ways in which to accelerate the final interruption of the circuit. Either the speed of the moving contacts must be increased (thereby increasing the percentage of uncarbonized oil in the path at the instant of time when the current is very small), or a very high-velocity jet of oil or other insulating medium must be interposed across the path of the current (thereby actually interrupting the continuity of the carbonized path).

*Reactances.*—I entirely agree with the author's views regarding the limited usefulness of reactances, and am of the opinion that effort should be directed towards the improvement of switchgear design rather than towards an undue increase of reactance. The development of switch design would seem to afford a very extensive field for the application of ingenuity, and it is a problem which calls for close collaboration between manufacturers and operating concerns. I see no reason why the rupturing power of oil switches should not be capable of improvement severalfold if time and money be spent upon experimental research under working conditions with apparatus of radically novel type.

*Economical section of mains.*—The latter section of the paper is full of interest, but in my opinion very great caution should be exercised in attempting to apply the results deduced. The author is evidently fully alive to this, as he has inserted a saving clause in his concluding remarks. It must always be remembered that in designing the initial lay-out of a power scheme, the ultimate scope of the business cannot be foreseen with any approach to accuracy, and the problem is therefore one in which the assumptions are far less precise than the methods of calculation which can be applied. One of the advantages of overhead working is the ease with which the pressure

can be increased at small cost, and it is often sound policy Mr. to install switchgear suitable for such an eventual increase and transformers arranged with windings connected in parallel, which can subsequently be connected in series, or in delta, which can later be connected in star. The usual procedure would be to gauge as closely as possible the ultimate scope of the business and then to select such pressures and standardize such sections of main as will meet these eventual conditions without undue multiplication of circuits and switches.

*Miscellaneous points.*—Under Section 2 (b), the author states that the balanced-current protective system and the split-conductor protective system (both of which are perhaps better termed differential protective systems) are able, by virtue of their instantaneous action, to isolate a faulty feeder with quite a low value of fault current. Whilst it is true that the relays operate very rapidly, the movement of the relay and the subsequent movement of the switch occupy several cycles, even with most modern designs, whereas the current flowing to a dead short-circuit rises to its maximum value within one-half cycle. It is of course possible that in exceptional cases the resistance of the fault may take an appreciable interval of time to fall, but as a rule the fault closely approximates to a dead short-circuit. When the rate of dissipation of energy at a fault on a large system is realized, it becomes difficult to imagine any appreciable time lag. The effects are in the nature of an explosion. This fact renders it all the more important that the fault should be isolated in the smallest number of cycles, but it is unsound to assume that so-called instantaneous relays will eliminate the mechanical strain to which all apparatus in circuit with the fault is subjected at the moment of short-circuit. It is here that the use of a reactance is of value, because it would seem to be the only means by which to reduce these mechanical strains. I am in favour of the installation of such reactances in series with the generators, *i.e.* at the point where they can influence the entire system and can be installed at minimum cost and with maximum ease. An undue increase in reactance augments the voltage variation for a given change in load, and if the load comprises huge electric winders, as it does on the Rand, automatic control of the generated pressure becomes essential. This again renders it necessary that the cut-outs throughout the system should operate with minimum time element, otherwise the pressure regulators have time to affect appreciably the fault current at the moment when the switches are endeavouring to interrupt the circuit. My experience points to the conclusion that the combination of a reasonable amount of reactance in the generators themselves and/or in series with them, with automatic voltage regulators and instantaneously-acting differential relays, is thoroughly satisfactory, and that any deficiency in the operation of the switches should be removed by an improvement in the switch itself. I would also refer to the author's remarks in subsection (c) under the heading I(a) "Mains." Apart from any question of inequality in current, the parallel operation of cables and overhead lines is bad practice. It certainly conduces to surging, and it permits induced effects of lightning to pass from overhead lines to the underground system. In this contribution to the discussion, I have touched upon only a few of the more general conclusions to be drawn from experience on the

Rand. Many details of a purely practical nature would hardly fall within the scope of the paper.

Mr. J. R. BEARD (*in reply*): As mentioned in my reply to the discussion before the Institution<sup>2</sup> Mr. Price is one of the pioneers in the design of high-pressure distribution systems. In conjunction with Mr. Merz he was responsible for the important early development work on the North-East Coast and also the invention of the differential principle as applied to protective devices which resulted in the first commercially satisfactory solution of the problem of operating an interconnected system. For the last six years Mr. Price, as engineer to the Victoria Falls and Transvaal Power Company, has had a further unique opportunity of studying the design of such systems and of translating his ideas into practice on a system double the capacity of that on the North-East Coast, and under operating conditions very much worse than any experienced in this country or even in America and on the Continent. Hence it is obvious that the very full details he has given of his experience on the Rand must be most carefully considered, as they will give engineers in this country an idea of the conditions that are likely to be met in the future as our systems extend.

Mr. Price first discusses the lay-out of distribution systems, and I am pleased to note that his later experience under the more onerous conditions of the Rand has not in any way diminished his confidence in the interconnected system and in the possibility of its development on the largest scale. I am glad attention has been drawn to the importance of earthing the neutral point in order to facilitate the operation of protective gear and to prevent high-frequency surges. This matter was not referred to in the paper, as it was very fully discussed three years ago in connection with a paper by Mr. Peck.<sup>†</sup> Even at that time there was a strong feeling in favour of earthing the neutral, and at the present time the consensus of opinion is that there is no question as to the desirability of doing this under normal conditions. In fact the only case which can be made out for an unearthed neutral is the somewhat doubtful one of non-duplicate overhead transmission lines such as are in use in America, which are often 50 to 100 miles long and traverse uninhabited country. In such cases a fault may take days to find, and it is frequently possible with an unearthed neutral to maintain the service with a fault on one phase until the fault can be found and removed. It is, however, most useful to have Mr. Price's definite confirmation from actual experience that an unearthed neutral promotes serious surges. An almost equally important point, which is also mentioned, is that if instantaneously-acting protective gear is used and the neutral point earthed, the majority of faults are now faults to earth and are therefore much less severe. This is usually assisted by the addition of resistances in circuit with the neutral connection, but even if no special resistances are introduced there is usually sufficient earth resistance at the fault and at the earthing-plates to effect a material reduction in the fault current. The insertion of resistance at the neutral point must be done with caution, as if it is too great and a high-resistance earth-fault occurs, the fault current may not reach a value high enough to operate the protective devices. This may be guarded against by installing an automatically operated

switch which short-circuits the earthing resistance through Mr. Beard, the medium of a definite time-element relay if the fault is not cleared before a time has elapsed which is fixed by the setting of the relay.

In dealing with differential protective gear I do not think Mr. Price does justice to the advantages of the split-conductor system. As mentioned in the paper, both pilot-wire and split-conductor protection have been used on an extensive scale on the North-East Coast. Consequently it has been possible to obtain a very good idea of their relative merits, and for such a system split-conductor protection has been proved to have the balance of advantage for feeders. The experience on the Rand on the other hand has been limited to pilot-wire protection only. Mr. Price particularly points out that the two outstanding characteristics of a differential protective gear are, first, its instantaneous action and, second, its perfect discriminating properties which are entirely unaffected by the highest overload. Of course no system of protection can claim the literal fulfilment of such onerous conditions, but it is in just these characteristics that the split-conductor system shows its superiority. It can operate with much smaller fault currents, and therefore with more certainty and speed, since faults usually take a measurable period to grow, even if it is only a few cycles. It can also withstand much heavier straight-through currents without being affected. This is at once evident when it is appreciated that any differential apparatus is dependent on the balance which can be obtained with the heaviest straight-through current. In the case of the split-conductor system the two currents, the differential effect of which operates the gear, are directly balanced against each other, whereas with the pilot-wire system the two currents are balanced through the agency of current transformers and long pilot wires. The current transformers are difficult to balance magnetically under heavy currents owing to saturation of the iron, while if attempts are made to obtain a straight-line characteristic up to very heavy currents by increasing the air-gaps, the power obtainable from the transformers rapidly falls. The pilot cables also introduce difficulties not only from the point of view of maintenance and cost, but also due to capacity currents, which are aggravated by the peaked secondary voltages caused by saturation in the transformers. The design of such protective apparatus is therefore a rather complicated compromise between diverse influences. These difficulties do not arise to the same extent in the case of transformer and generator protection, and for these the pilot-wire system is certainly the best, and even for feeder protection it has been developed to a point at which it is quite workable on the largest systems and is the only reasonably efficient alternative to the split-conductor system. Mr. Price particularly criticizes the use of split-conductor protection for overhead lines, and the multiplication of conductors is certainly some disadvantage, although with the more recent designs where both splits are carried on the same insulator this is not so important, as the number of insulating points is not increased. Apart from this the split-conductor system has a greater advantage on overhead lines than it has on cables, owing to the fact that it can be set for fault currents only 20 per cent, or even less, of the corresponding settings with the pilot-wire system. Reference to my previous remarks on the high resistance

\* See page 229.

† *Journal I.E.E.*, vol. 50, p. 150, 1913.

Mr. Beard. of earth faults on overhead lines\* will at once indicate the importance of this, and on large systems it is almost impossible to set pilot-wire protection so that it will operate with certainty under high-resistance earth-fault conditions and at the same time not operate with the maximum possible straight-through currents. Probably Mr. Price has not been troubled very much from this cause owing to the fact that his system is almost entirely overhead, and therefore most of his faults will be to earth and the straight-through currents limited.

In view of the peculiar conditions on the Rand Mr. Price has the opportunity of obtaining more experience with lightning protective gear in a week than engineers in this country can obtain in many years. I therefore read his remarks on this subject with very great interest, and they are a striking confirmation of the views, based on limited experience, to which I have referred previously.† In short, Mr. Price, after all his experience, is unable to state definitely that lightning protective gear reduces the trouble from lightning, and he recommends that money should be spent on an increased factor of safety for apparatus in general rather than on a multiplication of lightning protective gear. It should also be remembered that lightning protective gear cannot be treated in a passive manner. It is not correct to take the attitude that, even if it apparently does no good, it may be as well to provide it since it will do no harm. Mr. Price tells us of certain troubles which such gear may cause, and it is obvious that additional apparatus means additional risk, more particularly if it involves a spark gap. I do not know whether Mr. Price has tried the effect of taking his overhead lines into sub-stations through short lengths of underground cable as recommended by Mr. Hunter in the discussion on Mr. Welbourn's paper on overhead lines.‡ If so, it would be most instructive to have some information as to the results under the Rand conditions. As I have previously mentioned, this method seems very satisfactory in this country.

Mr. Price gives at some length his experience with switchgear, and on the whole this bears out the general views I have expressed in the paper, but in two cases I am not in entire agreement with him. If, as I think is probable, the inertia of the oil plays a more important

part in wrecking switch tanks than the explosions of the Mr. hot gases on meeting the air, the exclusion of air from the internal portions of the switch and the provision of air-buffer chambers will not be of much assistance and, as Mr. Price points out, is a relatively expensive arrangement. Baffling the path of the gases will certainly tend to increase such inertia stresses, but the problems of switch design are so far from solution that it is impossible to say whether such increases of pressure may not be advantageous if only the tanks are strong enough to resist them. The other point I am doubtful about is the suggestion that the number of breaks should be increased. It is generally known that under short-circuit conditions on high voltages the voltage-drop across the arc is small relatively to the drop in the rest of the circuit, and consequently if the number of breaks is doubled the short-circuit current is not appreciably reduced, while the energy dissipated in the switch is doubled. There is thus more likelihood of a weak switch failing, and even if the switch has an ample margin of strength it is doubtful whether there will be much more tendency for the circuit to be more quickly broken. Mr. Price's criticism of the value of utilizing the magnetic repulsion of the currents at the arc has been already dealt with in my reply to Mr. Tallent-Bateman.\*

The whole of the discussion upon the switchgear section of the paper has emphasized the uncertain nature of our existing knowledge of the phenomena which take place in the oil switch, and there is no doubt that this is one of the most pressing and important problems in heavy electrical engineering. It is engaging the careful attention of engineers abroad, as is shown by the recently published report of the Association Suisse des Electriciens,† which although it does not attempt to deal with short-circuit conditions is yet most valuable as an attempt to put oil-switch phenomena on a theoretical basis and to check such theory by experiment. The subject is one in which the Institution might, through its Research Committee, play a very valuable part, and I would suggest that consideration should be given to its claims when the resources at the Committee's disposal permit of extensions to the scope of its investigations.

\* See page 294.

† Ibid.

‡ *Journal I.E.E.*, vol. 57, p. 305, 1914.

\* See page 437.

† Bulletin No. 8, 1913; abstracted in the *Electrician*, vol. 76, p. 717, 1910.

## INSULATING OILS.

Early in 1913 the Research Committee of the Institution appointed a Sub-Committee to consider the properties and methods of testing Switch and Transformer Oils. Letters were sent to a number of manufacturers and users of oils, and to Universities, and the replies received were reviewed in an interim report by Mr. W. Pollard Digby in January 1915.

The Sub-Committee have considered the suggestions received with regard to the proposed tests, which in the first place are being limited to Transformer Oils. An abbreviated account of the tests, most of which have been in practical use for some time, will be found below. The points that now require investigation are:—

(1) How far are the results consistent when made by different observers on the same sample of oil?

(2) Could the results of the tests be relied upon to indicate with certainty the behaviour of the oil under practical working conditions?

The Institution has received a grant from the Advisory Council for Industrial Research for this work, and the Sub-Committee propose therefore to put the experiments in hand at once, especially in view of the delays caused by the war.

The Sub-Committee desire to express their indebtedness to Mr. Pollard Digby for the services rendered by him in examining the information received and drafting the first report, and to the small Committee consisting of Messrs. A. C. Everest, A. C. Michie, and T. C. Thomsen who prepared the draft of the tests.

In order to judge the suitability of an oil for use as a cooling insulating medium, it is necessary to know its characteristics in the following respects:—

- (1) Tendency to sludge.
- (2) Loss by evaporation.
- (3) Flash point.
- (4) Viscosity at different temperatures.
- (5) Chemical reactions.
- (6) Density and coefficient of expansion.
- (7) Cold test (solidification).
- (8) Moisture absorption.
- (9) Dielectric strength.
- (10) Specific resistance.
- (11) Thermal transference.
- (12) Specific heat.

The detailed methods of investigation for each characteristic recommended in the following pages, may be first briefly reviewed.

## GENERAL REVIEW.

**Sludging.**—The object of this test is to obtain an idea of the tendency of the different oils to form solid deposits when they are subjected to the action of heat and air. This action is considerably influenced by the presence of certain metals. The method recommended is a modification of that used by Dr. Michie.† The oil contained in a flask is

subjected to the action of heat and oxygen for a given time, a piece of the metal in question of given surface area being present in the oil during the test. It would be of interest to obtain comparative figures for copper, iron, lead, tin, zinc, and aluminium, and, in view of the importance of copper in electrical work, data should also be obtained for tinned copper, silver-plated copper, and copper covered by insulating material such as cotton.

Besides the formation of solid deposits in the oils after these have been subjected to the conditions of the test, note should be made of any corrosive effects on the metals, the formation of water and acids, and the extent to which the oils have darkened in colour. The depth of colour of the oil can be accurately measured in degrees on a permanent colour scale by means of Lovibond's tintometer No. 7 set for standardizing merchantable petroleum.

**Loss by evaporation.**—Two different methods of carrying out this test are described. A definite volume of oil is heated in a beaker at 100° C. for 8 hours. In one method the body of the beaker is immersed in the heating bath, its open mouth being exposed to the air of the laboratory but shielded from draughts. In the second method the beaker is carried in a revolving tray in a hot-air oven. The result is expressed in terms of loss of volume and ratio of surface to volume of oil, the height of beaker wall above oil surface at the commencement of the test being stated.

**"Closed" flash point.**—The temperature at which vapours accumulating above the oil in a closed vessel become inflammable is determined by means of either the Pensky-Martens or Gray's instrument. The oil is rapidly heated to about 25 degrees C. below its suspected flash point, the heating being continued beyond this at the rate of  $2\frac{1}{2}$  to 3 degrees per minute. At each additional degree of temperature the cover is opened and a flame inserted. The lowest temperature at which flash occurs is thus determined.

**Viscosity.**—The standard method in Great Britain for this determination is that of Redwood, which notes the time in seconds required for a definite volume of oil to run through an aperture of fixed dimensions. Measurements are made at 15.5° C., 50° C., and 80° C.

**Chemical reactions.**—The oil is tested for acidity and alkalinity. An iodine test is also recommended, as it is believed that this test gives a good general indication of the tendency to sludge.

**Density and coefficient of expansion.**—The density is determined at the three temperatures 15.5° C., 50° C., and 80° C., by means of specific gravity bottles or pycnometers, preferably of the Sprengel tube type. From this data the coefficient of expansion is obtained.

**Cold test.**—This test determines the temperature at which the oil commences to congeal. A knowledge of this characteristic is of importance in connection with oil switches used in exposed situations and cold climates.

**Moisture absorption.**—This test is made to determine the tendency of an oil to absorb moisture from the atmosphere,

\* *Journal I.E.E.*, vol. 53, p. 146, 1915.

† *Ibid.*, vol. 53, p. 213, 1915.

and is made by taking dielectric (breakdown) tests upon the originally dry oil after successive intervals of exposure.

*Dielectric strength and specific resistance.*—These are familiar laboratory tests.

*Thermal transference.*—A certain amount of information is available regarding the relative cooling effects in a transformer with oils of different viscosities, but it is felt that more exact information would be of value and a method of investigation recommended by the National Physical Laboratory is here described in detail.

*Specific heat.*—The method of performing this test is left to the judgment of individual experimenters. Data should be obtained at 15.5°C., 50°C., and 80°C. Reference is given to published data upon this subject. It is suggested that specific heat tests at 15.5°C. might with advantage be made upon the oils both in their original condition and after drying, but for the test at higher temperatures, dried oil (see Section 10) should be employed.

## TESTS.

### I(A).—SLUDGING TEST.

This investigation should be conducted as follows:—

One hundred cubic centimetres (100 cubic cm.) of the sample are introduced into a clean, dry, round-bottomed flask, having a neck 11 in. to 12 in. (28.0 to 30.5 cm.) long and  $\frac{3}{4}$  in. (19 mm.) internal diameter, and a bulb of 2.75 in. to 3 in. (70 mm. to 76 mm.) diameter which has a capacity of 200 cubic cm.

Next is introduced a piece of pure sheet copper having a "planished" surface (bright rolled and polished) and a thickness of 0.004 in. (0.1 mm.) and measuring  $1\frac{1}{2}$  in.  $\times$   $2\frac{3}{8}$  in. (3 cm.  $\times$  6 cm.). A fresh piece of copper should be used for each test. The total area of the copper, which equals 2.82 sq. in. (18.19 sq. cm.), is immersed in the oil.

To introduce the strip it is wrapped round sufficiently to overlap itself slightly and to slide easily down the neck. The copper strip must be so bent that when in the flask the edges spring apart leaving an opening about  $\frac{1}{4}$  in. (6 mm.) wide to facilitate circulation. The coiled strip stands vertically on the bottom of the flask. Before introduction, the surface of the copper is carefully polished clean by means of wash-leather and a little soft polishing paste.

The whole of the bulb of the flask is immersed in an oil bath, and the neck passes through a hole provided in the lid of the bath. The bath can be heated by gas or electric current, and must be fitted with a thermostat heat-regulating device and a motor-driven stirrer, so that the temperature is even throughout and can be maintained constant to within  $\pm 1$  degree C. of the selected temperature.

The neck of the flask which projects above the lid of the oil bath is water-cooled by means of a water jacket 10 in. or 11 in. (25.4 cm. to 27.9 cm.) long connected to the water supply in the usual manner. The mouth of the flask is fitted with a rubber bung having two holes and carrying two glass tubes of 0.157 in. (4 mm.) internal diameter, which are respectively the exit and inlet tubes for passing a stream of oxygen through the oil.

The exit tube ends nearly flush with the inside of the bung, whilst the inlet tube reaches to within  $\frac{1}{8}$  in. (3 mm.) of the bottom of the flask, and passes axially through the

cylinder of copper, which thus aids in the distribution of the oxygen throughout the body of the oil. The portions of the exit and inlet tubes outside the flask are bent to a convenient angle for connection to the following apparatus:—

Before entering the flask the oxygen is made to bubble through a layer of oil of 2 in. (51 mm.) depth, contained in a "tell-tale" bottle of 8 oz. capacity which is fitted with a 2-hole rubber bung carrying two glass tubes for inlet and exit of the gas.

The inlet tube is of 0.313 in. (7 mm.) internal diameter, and reaches to within  $\frac{1}{2}$  in. (1.3 cm.) of the bottom of the bottle.

The exit tube is of 0.157 in. (4 mm.) internal diameter, and projects not more than  $\frac{1}{4}$  in. (6 mm.) inside the bottle. It is coupled up to the inlet tube of the flask.

The inlet tube of the tell-tale bottle is joined up to the following purifying train.

The oxygen supply as purchased should be of not less than 99 per cent purity, and it is further purified before entering the tell-tale bottle by passing it through three wash bottles containing respectively caustic soda solution of specific gravity 1.355, 10 per cent silver nitrate, and pure strong sulphuric acid.

The sample in the flask having been placed in the oil bath and joined up to the tell-tale bottle and oxygen supply, is then raised to the temperature selected for the experiment. It is maintained at this temperature for a continuous period of 45 hours, and during the whole of this time a steady stream of oxygen is passed through it. The rate of flow of the oxygen, as shown by the bubbles at the 7-mm. inlet tube of the tell-tale bottle, is adjusted to 3 bubbles per second; this is equivalent to 6.7 litres (0.23 cubic ft.) per hour measured at 20°C.

For the purposes of this research each sample should be tested at 60°, 70°, 80°, 90°, 100°, 110°, and 120°C., duplicate tests being taken at each temperature. The amount of sludge, or, if no sludge forms, the change of colour (darkening) produced, is determined for each test.

At the end of the 45 hours' reaction, the oil is cooled and diluted with petroleum spirit in the ratio of 3 volumes of petroleum spirit to 1 volume of oil, taking care that all the deposit is removed from the flask. The whole quantity is mixed and transferred to a beaker, which is then covered and allowed to stand 12 hours for the sludge to settle out completely. The liquid is then decanted through a fine grained filter paper and the precipitate of sludge thoroughly washed on to the paper with petroleum spirit, and further washed until free from oil. The petroleum spirit used for the experiment should have a specific gravity at 15.5°C. of 0.70 to 0.72, and not less than 75 per cent by volume should distil over below 110°C. (230°F.).

By means of hot benzol (pure benzene, C<sub>6</sub>H<sub>6</sub>, specific gravity at 15.5°C., 0.885) the sludge is then washed from the filter paper into a weighed vessel and its weight ascertained after evaporating off the benzol and drying at 100°C. until of constant weight. (As the residue when dry is usually very hygroscopic, the evaporation should be commenced on a water bath and the drying completed in a water oven.)

Knowing the specific gravity of the oil and the volume taken for the test, the result can be calculated out and should be stated as the percentage by weight of sludge

yielded by the oil. All the results obtained for each particular sample are then plotted on squared paper with temperatures as abscissæ and percentages of sludge (by weight) as ordinates.

#### FIG. 1.—CHANGE OF COLOUR.

In those cases in which no weighable precipitate is obtained, the change of colour should be recorded.

An instrument specially devised for this purpose is Lovibond's "tintometer" known as "No. 7 set for standardizing merchantable petroleum." By means of this instrument the depth of colour in the sample under investigation is matched to a corresponding shade in a series of coloured glasses numbered according to the depth of colour. The instrument is listed by Messrs. Baird and Tatlock.

#### TEST 2(A AND B).—EVAPORATION (LOSS ON HEATING).

The evaporation is determined by ascertaining the loss in weight produced by heating a standard weight of oil for 8 hours at 100° C.

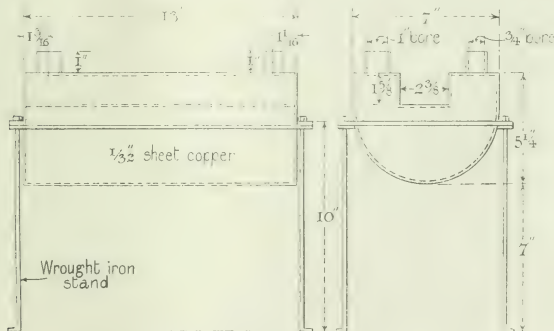


FIG. 1.—Dr. Michie's apparatus for determining loss on heating.

Two different methods now in use for this purpose are described below, namely:—

- Test 2(A) ... Dr. Michie's (toluene vapour-bath method).  
 Test 2(B) ... B.T.H. Company's (rotating oven) method).

#### TEST 2(A).—DR. MICHIE'S METHOD OF DETERMINING THE LOSS ON HEATING.

The apparatus used is illustrated in Fig. 1, which is almost self-explanatory. The apparatus consists of a vapour bath constructed of 1/32 in. sheet copper bent cylindrically into a circle with its sides continued upwards in a straight line so that it is "D" shaped. This is fitted with ends and a lid which has a trough with vertical sides and of 1 3/8 in. depth by 2 3/8 in. breadth sunk (formed) in it. This trough runs longitudinally down the centre line of the lid and is 13 in. long, and the "D" shaped portion thus forms a vapour jacket surrounding the trough.

The lid is also provided with two holes, 1 in. and 3/4 in.

diameter respectively, on opposite sides of the trough and at opposite ends of the vapour jacket. These are fitted with tubes projecting to a height of 1 in. above the surface of the lid, and are respectively intended to carry a short condenser and thermometer to prevent the loss of toluene and to control the production of the vapour.

The trough is filled with lead shots of 0.064 in. diameter, and the interior of the boiler or vapour jacket is about two-thirds filled with commercially refined toluene. The whole bath is set up on a wrought iron stand having legs of 10 in. length, so that gas jets can be put under the boiler for making the toluene boil vigorously.

The boiling point of toluene at ordinary atmospheric pressure is 110° C., but the loss of heat in transmission makes the temperature of the oil under test only 100° C. The temperature of the oil should be checked by embedding one or more thermometers in the shot, or, if preferred, by putting a "blank" test in, with the thermometer placed in the oil.

To avoid variations due to draughts of air passing over the crucibles containing the tests, the trough can be pro-

vided with a protective frame 6 in. deep × 12 in. × 7 in. made in a separate and removable piece which is laid on the top of the bath. The use of a vapour-heated trough ensures a steady and definite temperature and avoids complex heat-regulating apparatus.

The standard conditions of the test are as follows:—

Into a weighed crucible of glass, quartz, or porcelain, of 1 1/2 in. diameter × 1 1/2 in. depth is placed 5 cubic cm. (roughly 48 grammes) of the oil; and the total weight is determined by re-weighing.

The crucible is then embedded right up to its lip in the lead shot in the trough and heated for the standard time of 8 hours.

When cold the crucible is re-weighed and the result expressed as loss of weight in grammes per 100 sq. cm. of surface exposed. With crucibles of the above dimensions, the surface area of oil exposed is 11.34 sq. cm. The result is finally expressed in terms of loss of original volume and the ratio of surface exposed to volume of oil, the height of

the beaker wall above the oil surface at the commencement of the test being also stated.

Several tests can be performed simultaneously.

In the original design (which was due to Mr. Alex. Duckham, of London) the cage was driven by clockwork and the oven was heated by gas.

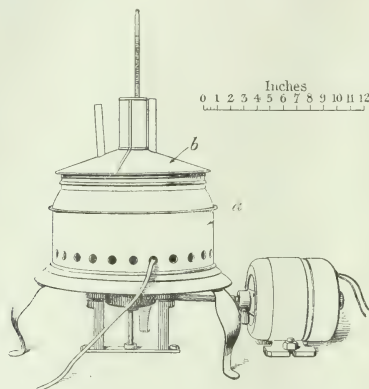


FIG. 2.—B.T.H. apparatus for determining loss on heating.

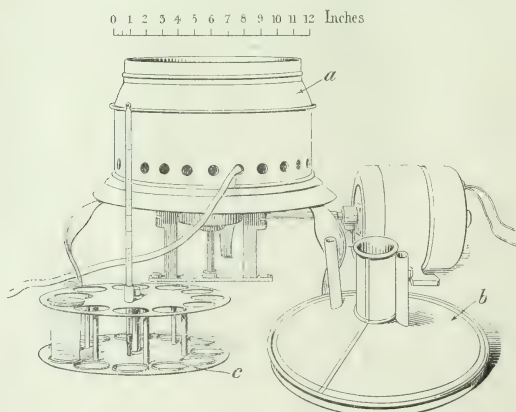


FIG. 3.—B.T.H. apparatus for determining loss on heating.

#### TEST 2(b).—B.T.H. METHOD OF DETERMINING THE LOSS ON HEATING.

This method aims at obtaining very uniform conditions of heating by the use of an air oven containing a rotating cage for carrying the test beakers.

The British Thomson-Houston Company have found it preferable to substitute an electrical drive for the rotating cage and electrical heating in place of gas. Figs. 2 and 3 show the apparatus. In Fig. 2 the apparatus is closed for running, whilst in Fig. 3 it is opened and the cage

"c" removed to show how the beakers are arranged and the relative size (indicated by the 12-in. rule above the top of the casing). The cage carrying the beakers works inside an iron casing "a" with holes at the side and provided with a removable lid "b" having a chimney at the top to permit of gentle ventilation. The latter is due to the heat and slow movement of the cage, and no trouble from draughts of air can arise. The cage "c" accommodates 12 beakers of the standard size, viz.  $3\frac{1}{4}$  in. to  $3\frac{1}{2}$  in. tall,  $1\frac{1}{2}$  in. to  $1\frac{3}{8}$  in. diameter at the top, and  $1\frac{1}{8}$  in. diameter at the bottom.

Two grammes of oil are weighed into each beaker. This produces a layer of oil of roughly  $\frac{1}{8}$  in. (3 mm.) depth and having an exposed area of 1.8 sq. in. The height of the beaker relative to the depth of oil prevents loss by "creeping" of the oil up the sides and reduces to a minimum any effect of air currents in the oven.

In the original clockwork apparatus the cage when fully loaded performed 2 revolutions per minute, but the present electrical drive is at the rate of 6 r.p.m.; a variation of  $\pm 1$  r.p.m. does not introduce errors in the tests.

The heating unit is situated in the plane of the holes in the side of the casing. It rests on insulation which lies on a sheet of steel forming the bottom of the casing, and above it and between it and the revolving cage is a false bottom which very loosely fits the casing and thus equalizes the temperature by preventing local convection currents rising from the heating unit.

The final results are expressed in the same way as in Dr. Michie's method (Test 2a) described above.

### TEST 3.—CLOSED FLASH POINT.

This is to be determined by means of either the Pensky-Martens or Gray's instrument, under the standard conditions as specified in Sir Boverton Redwood's book "A Treatise on Petroleum," 1913 edition (for Gray's tests see vol. 2, p. 269; and for the Pensky-Martens tests vol. 2, pp. 238 and 267). Standardized thermometers should be used for this test.

The following procedure in the method of employing the Gray apparatus has been found to yield satisfactory results in practice at the National Physical Laboratory.

A rough determination of the flash point is first made; a fresh sample of the oil is then put into the oil cup and is heated rapidly to within about 20 degrees of the flash point first observed. The rate of heating is then reduced to about  $2\frac{1}{2}$  degrees or 3 degrees per minute and the test flame is applied to the oil vapour at each degree rise in temperature, in the usual way, until the flash occurs; this temperature is then recorded and the necessary thermometer correction is applied. The mean of three concordant results on fresh samples of oil is taken as the desired flash point. In carrying out the test in this way, it is important that the stirrer should be continuously employed except while actually applying the test flame.

### TEST 4.—VISCOSITY.

The viscosity is to be determined by means of a standardized Redwood viscometer, at each of the following temperatures:—

15°C. (60° F.)    50° C. (122° F.)    80° C. (176° F.).

The method is given in detail in Sir Boverton Redwood's treatise "Petroleum and its Products," vol. 2, pp. 600-602 (Second Edition). Care must be taken in the use of the instrument at temperatures above that of the air.

The viscosity should be expressed as the time in seconds required for the outflow of 50 cubic cm. of the sample. Standardized thermometers should be used for determining the temperatures.

The tests should be made in duplicate and the mean result used for plotting a curve, with times of flow as ordinates and temperatures as abscissae. The variation between duplicate tests should not exceed  $\pm 1.0$  per cent.

### TEST 5.—CHEMICAL TESTS.

(a) Acidity; (b) Alkalinity; (c) Iodine value.

(a) *Acidity*.—25 grammes of the original oil are shaken up with 100 cubic cm. of neutral ethyl alcohol (containing 95 per cent by volume of anhydrous alcohol), 1 cubic cm. of a 1 per cent alcoholic solution of phenol phthalein indicator is added and the liquid titrated with aqueous N/10KOH (deci-normal caustic potash) and the result reported as the number of milligrammes of KOH (potassium hydrate) required per gramme of oil.

(b) *Alkalinity*.—25 grammes of the original oil are shaken up with 100 cubic cm. of warm distilled water, the liquid is cooled, and 1 cubic cm. of a 0.1 per cent solution of methyl orange indicator is added, and if the solution reacts alkaline it is titrated with N/10HCl (deci-normal hydrochloric acid), and the result reported as the number of milligrammes of KOH (potassium hydrate) equivalent to the acid used per gramme of oil.

(c) *Iodine absorption value. Hübl's process*.—This "constant" is determined by following the general directions for the Hübl method as described in "Chemical Technology and Analysis of Oils, Fats, and Waxes," by Dr. J. Lewkowitsch (vol. 1, p. 311, 1909 edition, Macmillan & Co.), but using from 1.0 to 1.25 grammes of the oil, with 10 cubic cm. of chloroform and 50 cubic cm. of the standard iodine solution, and allowing the reaction to proceed for not less than 18 or more than 24 hours.

It is generally conceded that the iodine values so obtained are accurate provided that an excess of iodine of not less than 100 per cent above that absorbed has been employed and that the test conditions are identical. It should be therefore noticed that taking an iodine value of 30 per cent (which would be exceptionally high for any mineral hydrocarbon oil for insulating purposes), the 50 cubic cm. of iodine solution provided an excess of iodine of 240 per cent above the amount absorbed.

The Hübl method is less violent in reaction than Wijn's, Hannus', and other methods for determining iodine values; and for cases where the value is expected to be low owing to dilution of the reacting body or bodies with excess of others of a different type (as in mineral oils) it is much to be preferred.

### TEST 6.—(A) DENSITY; (B) COEFFICIENT OF VOLUMETRIC EXPANSION.

These two determinations are combined in a way which only requires accurate specific gravity determinations of the oils, and a table of data giving the volumetric expansion

sion of pure water taken with its volume at 4° C. as unity (see Table 41A, p. 212 of vol. 1 of "Physico-Chemical Tables," by J. Castell Evans).

The density is to be determined by means of specific gravity bottles or pyknometers at each of the following temperatures, and compared with pure water at the same temperatures.

15° C. (60° F.)      50° C. (122° F.)      80° C. (176° F.).

A pyknometer of the Sprengel tube type will probably be found very convenient.

With due care the probable errors on the specific gravity should not exceed  $\pm 0.001$ . If thought desirable, additional tests at any temperature within the range 15° C. and 80° C. can be made. (After using specific gravity bottles or pyknometers for determinations at 50° C. or 80° C., sufficient time must be allowed for the glass to resume its original volume before again using them for a lower temperature determination.)

By the aid of the above data respecting the volumetric expansion of water, the volumetric expansion of the oils can be calculated over the range of temperature used. The results of the specific gravity should be plotted as a curve, with specific gravity as ordinates and temperatures as abscissae.

#### TEST 7.—COLD TEST.

For this determination a volume of 25 cubic cm. of the oil is placed in a thin-walled glass test-tube of 6 in. length and  $1\frac{1}{4}$  in. internal diameter (capacity = 150 cubic cm.). The oil must be free from moisture.

A cork carrying a standardized thermometer reading from -40° C. (-40° F.) to +40° C. (+105° F.) is lightly fitted into the mouth of the test-tube so that the bulb of the thermometer is situated in the centre of the oil. The graduations of the thermometer should be engraved upon its stem, and should read to  $\frac{1}{2}$  degree C.

The test-tube is then immersed in a suitable freezing mixture so that the whole of the oil is surrounded by the latter. The oil is stirred until nearly solid and then left until no sign of fluidity remains. The test-tube is then removed from the freezing mixture and allowed to warm slowly with constant stirring by a thermometer until the temperature is reached at which the oil will flow from end to end of the tube, which temperature is recorded as the cold test temperature.

During both cooling down and warming up, notes should be made respecting the general appearance of the oil—that is, whether the oil sets uniformly as a whole or shows crystals of solid paraffin separating out.

#### TEST 8.—MOISTURE (ABSORPTION).

The term moisture as here used excludes "free water," *i.e.* visible water or finely subdivided water or emulsions which will separate as distinct layers if the oil is permitted to stand undisturbed for say 48 hours in a room at 15° C. (60° F.) to 25° C. (77° F.). For such instances the term "free water" should be used.

It is considered that there does not exist any really accurate and satisfactory quantitative method for estimating the minute percentages of moisture held in solution by mineral oils, which causes them to be termed "undry" in the electrical sense. Drying by heating the oil to 100° C.

or 110° C. drives off some of the more volatile constituents of the oil as well as such moisture. Chemical methods are of no value.

The presence of moisture can be qualitatively demonstrated by means of the dielectric strength test, using the standard method given under Test 9. Therefore the object of the following test is to ascertain the relative powers of oils to absorb moisture from the atmosphere after they have been dried and proved to be so in the electrical sense by means of the standard dielectric test. Although this test is primarily qualitative, yet, since the qualitative effect of traces of absorbed moisture upon the dielectric strength is already known approximately, it can also be interpreted up to a certain point in rough quantitative terms.

The method of performing the test is as follows:—

Some of the oil as originally received is first tested for its dielectric strength by the standard method (Test 9).

Four and a half ( $4\frac{1}{2}$ ) litres of it in the same condition are then put into a clean dry enamelled iron pan which has a flat bottom roughly 12 in. in diameter and vertical sides 6 in. deep. This is then heated for 4 hours to a temperature of 100° C. It is then cooled and some of it tested by the dielectric test. The oil used for this test is rejected.

The 4 hours' drying at 100° C. is repeated and followed by a dielectric test. This process is repeated until no further significant increase in the dielectric test is produced. At this stage the oil is considered perfectly dry in the electrical sense. All portions of the oil which have been subjected to the dielectric test should be rejected; they are not fit for further use.

The oil remaining from the above tests is then exposed to the air of the laboratory for 1 hour, the wet and dry bulb readings are noted, and the dielectric strength again ascertained. Free access of air to the surface of the oil should be arranged for, but the oil must be protected from particles of dust, etc., during the whole testing process *i.e.* both during "drying" and "absorbing."

The remaining oil is now exposed to the air for 24 hours; wet and dry-bulb readings are taken at least twice during this period, and then the dielectric test is repeated.

This procedure of 24-hour exposures and testing is continued until the dielectric test has fallen to a value so low that the oil would be considered to be below a safe one for any insulating purposes (or the whole  $4\frac{1}{2}$  litres have been used up). The results are to be plotted as a curve having dielectric values as ordinates and time as abscissae.

NOTE.—If the value of oil required for each dielectric test is 250 cubic cm. (about  $8\frac{1}{2}$  oz.) 16 or 17 tests can be made from the quantity originally dried.

#### TEST 9.—DIELECTRIC STRENGTH.

This test should be made with  $\frac{1}{2}$  in. diameter (12.7 mm.) spheres with a separation of 0.15 in. (3.81 mm.). Duplicate tests should be made. The spheres can be made of brass, but a pure metal of high melting point such as platinum or tungsten would probably wear better. The electrodes should be immersed in the oil to a distance of not less than  $1\frac{1}{2}$  in. from the surface. The volume of the oil used per test should not be less than 250 cubic cm. (roughly  $8\frac{1}{2}$  fluid ounces). The temperature of the oil should be between 15° C. and 20° C.

The containing vessel and the electrodes must be made

absolutely clean and dry before performing each test, and great care taken to avoid any contamination of the next oil examined. For this reason horizontal electrodes are probably preferable, but whichever method is used it must be so arranged that the electrodes can be readily removed bodily from the containing vessel for the purposes of cleaning and drying them and adjusting the gap distance. If the electrodes become pitted by the action of the spark they should be renewed.

The voltage at which sparking first commences, and also that at which complete breakdown with continuous sparking occurs, should be recorded.

The oil used for this test should not be used for any other research tests.

#### TEST 10.—SPECIFIC RESISTANCE.

This test should be made upon the oil as received, and also after perfectly drying it in the manner detailed under "Moisture."

It is not thought necessary to specify the full details for this test, but it is very strongly recommended that the tests be always conducted upon very thin films of oil between electrodes in order to avoid excessively high values—the latter have no practical significance.

The temperature at which the standard specific resistance test is to be performed should be between 15° C. and 20° C., and as near 15° C. as possible with the apparatus.

NOTE: Additional tests should be made upon the oil in both the conditions named above, at higher temperatures up to say 120° C. and also with increasing and decreasing temperatures. The results so obtained would be of considerable interest, for it is probable that perfectly dried oil has the same "specific resistance-temperature" curve for ascending and descending temperatures. This point has not yet been proved.

#### TEST 11.—THERMAL TRANSFERENCE.

The cooling of a transformer by the flow of oil through ducts between the windings may be studied in its simplest aspect by a consideration of the following case.

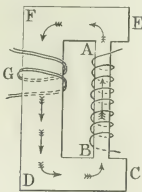


FIG. 4.—Thermal transference.

AB (Fig. 4) is a narrow pipe joined at the upper and lower ends to a wide pipe FD by the cross-pieces EF and CD. The vessel thus formed is completely filled with oil, the resistance to the flow of which is to be considered negligible, except in the tube AB. Now suppose that AB is heated uniformly, say by an electric winding as indicated, there will be a temperature gradient set up in the tube

from B to A. The decrease in density of the oil resultant upon this temperature rise will start a convection flow in the direction D B A F as indicated by the arrows. This convection flow will be maintained if at the upper end of the tube FD a cooling coil, G, is provided. There will thus be a system set up in which heat is transferred continuously from the tube AB to the cooler G.

In an ideal case we may consider that the temperature of the oil at B is  $T_0$  and that in its passage up BA it increases uniformly to  $T_1$ ; its mean temperature in AB is thus  $\frac{1}{2}(T_0 + T_1)$ . Further we will assume that on arriving at G the oil is immediately cooled to  $T_0$  so that the column of oil in FD has a constant temperature  $T_0$ .

If E is the energy supplied electrically to the oil in its passage through AB expressed in calories per second, we have

$$E = Q \sigma \cdot (T_1 - T_0),$$

where Q is the quantity of oil flowing in grammes per second through the tube AB,  $\sigma$  is the specific heat of the oil at a mean temperature  $\frac{1}{2}(T_0 + T_1)$ , and  $(T_1 - T_0)$  is the rise in temperature as previously stated.

Now Q, the quantity of oil flowing per second, may be expressed in terms of the dimensions of the tube and the physical constants of the oil by an application of Poiseuille's law, which gives

$$\frac{\pi P R^4 \delta}{8 L \eta},$$

where R and L are the radius and length of the tube AB respectively,  $\eta$  the coefficient of viscosity of the oil,  $\delta$  its density, and P the fall in pressure through the length L of the tube. For convenience  $\eta \delta$  may be expressed as  $\nu$  the coefficient of kinematical viscosity of the oil, and in the simple calculation given here  $\nu$  will be taken to be the mean value of the kinematical viscosity over the range  $T_0$  to  $T_1$ . A more exact result could be obtained integrating  $\nu = f(T)$  over the range  $T_0$  to  $T_1$ .

The above is based on the assumption that the flow is stream-line in character; this will generally be the case, but may be tested by the substitution of the requisite values in Osborne Reynolds' relation for the critical velocity.

The fall of pressure is obtained as the difference in weight of a column of liquid of unit cross-sectional area at a temperature  $T_0$  and that of a similar column at a mean temperature  $\frac{1}{2}(T_0 + T_1)$ .

This is  $P = \frac{1}{2} L \delta_0 g \alpha (T_1 - T_0)$ , where  $\delta_0$  is the density of the oil at a temperature  $T_0$  and  $\alpha$  is its coefficient of expansion.

$$\text{Hence } Q = \frac{\pi L \delta_0 g \alpha (T_1 - T_0) R^4}{16 \nu L},$$

and on elimination of Q between this and the original energy equation we obtain

$$\frac{E}{(T_1 - T_0)} = \frac{\pi g \cdot \sigma \delta_0 \alpha}{16 \nu} R^4$$

$$\text{or } \frac{E}{(T_1 - T_0)^2} = C \cdot f(\text{oil}) \cdot \phi \text{ (dimensions).}$$

When there is unit difference of temperature between the upper and lower ends of the tube the above equation becomes

$$F_{(1-1)} = C R^4 \cdot f(\text{oil}).$$

That is,  $E$ , the thermal transfer per unit difference of temperature, is equal to, for any given apparatus, an apparatus constant (viz.  $\pi g R^2/16$  in the simple case of a cylindrical tube) multiplied by a function of the physical properties of the oil. This constant for each oil may be termed its "coefficient of thermal transference" and is equal to  $\sigma \delta, a/\nu$ .

The efficiency of an oil in a transformer or in a test apparatus of the simple type outlined above may thus be determined by the value of the function  $\sigma \delta, a/\nu$ .

The foregoing reasoning is of course approximate, and before the results are accepted it would be necessary to test the validity of the final conclusion. If the relation were shown to be roughly true, the determination by direct experiment of either (1) the thermal transference coefficient as defined above, or (2) the values of the specific heat, the density and the coefficients of viscosity and expansion, would serve to decide the value of an oil for use in a transformer from the point of view of its cooling effect.

The above notes on Thermal Transference must be regarded as a suggestion for an experimental investigation, and the conclusions arrived at require verification at a convenient opportunity. In the meantime the Coefficient of Thermal Transference as defined by the function  $\sigma \delta, a/\nu$

might be employed in estimating the suitability of any oil of which the physical constants had been determined.

#### TEST 12.—SPECIFIC HEAT.

The method of performing this test is left to the judgment of individual experimenters, but it should be taken at 15° C. (60° F.). It would be advantageous to determine the effect of increase in temperature upon this value, over a range of temperature from 15° C. (60° F.) to 80° C. (176° F.).

Reference might be made here to the summary of the present knowledge upon the specific heat of hydrocarbons given in "Vademecum des Mineralöl-Chemikers," by Dr. Rudolf Wischin (1900 Edition, pp. 221-225), and in "Des Erdöl und Seine Versandtem," by Dr. H. Von Hofer (1912 Edition, pp. 53-54); also in "Untersuchung der Kohlenwasserstofföle und Fette," by Dr. Holde (1913 Edition, pp. 14-17).

It would be preferable to perform the specific heat tests upon the oils both in the condition as received and also after drying to a condition of perfect dryness in the electrical sense as detailed under Moisture (Test 8).

For the determination of the effect of temperature upon specific heat it would be preferable to use only the perfectly dried oil.

## NOTES ON ELECTRICAL WORK IN AUSTRALASIA.

By C. G. CALMAN, Student.

(Abstract of Paper received 28 May, 1915.)

#### ELECTRICAL UNDERTAKINGS.

Although electrical undertakings throughout Australasia may not have developed as quickly as those in some other countries, there is no doubt that they have expanded much more rapidly than the various communities which they serve. The larger cities have supply systems owned either by companies or by the municipalities themselves; and many of the municipalities adjacent to those owning power stations have entered and are entering into contracts to take a supply in bulk in order to distribute electrical energy within their own boundaries.

The last few years have seen a large number of small plants installed primarily for country-town lighting. These usually have a few motors connected to the mains, but up to the present the majority have had to rely upon the lighting load for the bulk of their revenue. Such plants are nearly always continuous-current installations with a secondary battery, and the prime-mover is frequently a gas engine, running sometimes upon town gas, or more often upon producer gas. The supply pressure is usually 220 to 240 volts two wire, or three wire with 440 to 480 volts across the outers. Unfortunately, some country towns

wishing to install such plants are hampered by the absence of proper State legislation. All the States in Australia are not on the same footing in this respect, in that some have an Electric Lighting Act. In Victoria, for instance, such an Act is in force and these small town installations have been completed in large numbers. On the other hand, New South Wales has no such Act, in spite of the representations which have been made from time to time to the Government by persons interested in the electrical industry.

Although this paper deals mainly with power plant, a few words about general illumination may be of interest. The introduction of the metal-filament lamp has of course had the same effect in Australasia as in other countries, and the so-called half-watt lamp promises to revolutionize lighting practice in certain respects, just as the one-watt lamp did some years ago. The maintenance of arc lamps under the prevailing conditions, apart from the high cost of labour, makes certain the general substitution of the nitrogen-filled lamp for the arc lamp.

The expansion of electric tramways during recent years has been in keeping with the growth of population. It is

of interest to note the work in hand for, and proposals concerning, the electrification of railways. The most important of these, and that for which construction work is already commenced, is the electrification of the Melbourne suburban railways. This will be one of the most important steam-road conversions that has so far been undertaken in any country, and it is estimated that the completion of the work as contemplated at present will take fully three years. The proposed electrification of the North Shore line in Sydney, and the Sydney Underground Railway and North Shore communication scheme, will be projects which are likely to be developed at an early date and promise to be large undertakings. The Tasmanian Government Hydro-electric Development will possibly introduce electric traction on railroads. In New Zealand the Lake Coleridge Hydro-electric Development will probably supply the electrified section of the East and West Coast Railway where it passes through the Otira Tunnel, some five miles in length, which is now under construction. The matter of electrifying the Christchurch-Lyttelton Railway, which passes through a lengthy tunnel, is also under consideration. These few examples are intended merely to give some idea of the work in hand and under contemplation as far as electric traction is concerned, and are not put forward as a complete statement of such schemes.

#### AUSTRALASIAN ELECTRIC SUPPLY SYSTEMS.

The mainland of Australia is in a very different position from Tasmania or New Zealand as regards water power. The latter have large numbers of streams or lakes which are admirably adapted for generating electric power, whilst the few isolated waters on the Australian Continent are of limited possibilities and are situated at too great a distance from the main distributing centres. This is so marked that the Sydney (N.S.W.) Municipal Council, which at present has the largest municipal electrical load in Australia, recently had under consideration the purchase of a coal-mine anywhere within a radius of 50 miles of Sydney, the idea being to transmit to Sydney electrical energy generated on the coal-field, instead of bringing coal to the generating station in Sydney as at present. Taking into account that the bulk of the power used in New South Wales is used on the coast line and within a comparatively short distance of the various large groups of coal-mines, and also in view of present-day developments in long-distance transmission and the perfection of e.h.t. apparatus, it seems only reasonable to assume that within a comparatively short time the New South Wales coal areas will be the sites of large generating stations working in conjunction with one another.

Other localities are not so favourably situated in respect to coal supplies and concentration of load, and will continue with scattered generating stations. Most of the inland towns, as mentioned previously, use suction-gas plants, and as the loads in such places are usually very limited, this type of plant is likely to be retained. The cost of coal at most of the country towns is prohibitive, and as wood fuel is continually becoming dearer owing to the exhaustion of near-by supplies, the suction-gas plant, operated upon coke or charcoal, shows to advantage for such work.

If small alternators could be operated satisfactorily in

parallel when driven by single-cylinder gas engines, this would permit of an alternating-current supply in certain cases where it might be advantageous. Numbers of small towns operate their pumping plants by electric motors, and more would be permitted to do this, or be able to do it more economically, if the supply voltage could be efficiently stepped up or down. Although continuous current is generally best suited to the requirements of the country towns, the driving of alternators in parallel by internal-combustion engines of a less costly type than the multi-cylinder engine would be the best solution in some instances.

There are some mining districts in Queensland and elsewhere which might to advantage be provided with electrical energy from large central stations. Such arrangements may be expected when the mines to be served are further developed and more improvements have been made in long-distance transmission apparatus. The absence of water power makes any such schemes dependent upon coal and wood fuel or coke. In the case of proximity to a coal-mine with coke ovens, gas engines will probably play an important part. The cost of oil fuel is too high and uncertain for such fuel to be used to any considerable extent in Australia.

In New Zealand and Tasmania the Government hydro-electric schemes will supply large areas. In the former country the development of a number of head waters was decided upon and a definite yearly capital appropriation fixed for such development. The first of these schemes, that of Lake Coleridge in the South Island, is now completed, and it is to be hoped that the results will prove a strong incentive to push ahead with the programme mapped out. In New Zealand the Government is not the only party engaged upon this work. The Dunedin Council have had their plant at Waipori in operation for some considerable time. Several years ago the Ross Goldfields harnessed the outfall of Lake Kanieri, 25 miles distant from their mine, and there has recently been completed the plant of the Waihi Gold Mining Company, which has utilized the Hora Hora Rapids and erected a transmission line about 50 miles long to supply their mine and mill. The Mount Lyall Mining Company have also recently completed their Lake Margaret scheme in Tasmania. Apart from these larger undertakings there are numerous smaller water-power installations supplying various townships throughout both New Zealand and Tasmania, and it is not unreasonable to hope that the near future will see practically the whole of New Zealand and Tasmania supplied from large stations possibly working upon common networks.

As far as electricity in the service of agriculture is concerned, practically nothing has been done up to the present.

#### COMMERCIAL ELECTRICAL WORK.

Under this heading it is proposed to note a few aspects of Australasian conditions from the point of view of the electrical contractor, and not so much from that of the manager of a supply undertaking. The majority of the electrical plant installed in Australasia is imported. It might almost be said that the whole of it is imported, as at present there is really only one firm in Australasia which attempts generator and motor manufacture. There

are of course numerous small workshops which make up switchboards from imported parts, and which construct various small electrical appliances, control gear, heating and cooking apparatus, etc., and carry out repairs; but beyond this there are practically no electrical workshops. The supply of electrical plant and goods is therefore mainly in the hands of agents for, or direct representatives of, the electrical manufacturers of other countries. The distance of these representatives from the manufacturing concern creates problems which are peculiar to countries removed so far from the manufacturer.

The most pressing need is for uniformity in the distribution systems. Whilst the want of this might not give rise to much inconvenience in manufacturing countries where machines of small and medium size for any voltage, frequency, etc., could be delivered within a few weeks of the order being placed, such is not the case in Australasia. When a machine is imported it is a matter of months before delivery can take place, and this delay is the cause of a great deal of inconvenience and waste of money. The obvious remedy is for contractors and agents to carry local stocks from which they can give immediate delivery of any small or medium-size machine. The difficulty here arises, however, that if stocks were carried for all the systems they would be found extremely large and unprofitable. Consequently only such stocks are carried as are found sufficiently saleable to warrant their existence, and such undertakings as are unprovided for by these have either to carry their own stock, keep stand-by machines, or put up with long delivery periods.

The demand for continuous-current machines is mainly for pressures between 220 and 240 volts, or 440 and 480 volts. In the case of alternating-current supplies, practically only 50-cycle systems are catered for from stock, but both single-phase and 3-phase motors are required. As regards single-phase, the voltages are 200/400 volts 3-wire. The 3-phase demand has been created mostly by 415-volt systems. It is to be hoped that no more single-phase systems will be installed for power supply. If the above pressures were universally adopted it would tend towards better conditions for both suppliers and users of electrical plant.

Despite a high tariff on all electrical machines and the further preference given by some of the Government Departments to Australian products, the local output of machines has been exceedingly small, and also restricted as regards size and variety of types. The great difficulty in machine construction, as well as in many other businesses throughout Australia, is in obtaining suitable labour at a reasonable wage; and even when secured, the industrial disputes, which are so rife, have to be contended with.

The manufacture of panel-type switchboards presented a different aspect from that of machine manufacture until quite recently. The tariff provided a duty of 20 per cent on complete switchboards, and no duty on instruments, switches, etc., of United Kingdom manufacture. This arrangement, coupled with the high cost of sea freight on complete switchboards, and the extra packing costs, risk of breakage, etc., prompted the local construction of switchboards from imported parts. Suitable marble and slate could be obtained from importers and merchants at satisfactory prices, and the concerns undertaking

switchboard manufacture could usually compete easily with imported switchboards. It should be understood that these remarks apply only to the more simple switchboard work. Complicated, large-capacity, or extra-high-tension alternating-current switchboards have necessarily been imported complete, as none of the local shops are laid out to handle such work. Quite recently the tariff on individual switchboard parts has been altered considerably. For instance, switches, fuses, circuit breakers, etc., which previously were free of duty if made in the United Kingdom, are now dutiable at 20 per cent even when imported separately. The effect of this will be to place the local workshops at a disadvantage, as there is now a smaller difference than previously in the amounts of duty payable on component parts and on complete switchboards.

With regard to specifications for plant to be installed in this country, there are a few points of importance which are not always recognized, although their general recognition is more marked latterly. One of these is the high atmospheric temperature obtaining in Australia, and especially in Queensland, the Northern Territory, and the inland districts of all States on the mainland. How absurd is a reference air temperature of 25° C. for, say, Queensland can be appreciated when it is remembered that maximum shade temperatures of 110° F. (43½° C.) are common and are sometimes exceeded. Although it would be unreasonable to expect such a high figure for an international reference air temperature, the necessity for the abandonment of 25° C., and possibly even 35° C., is apparent. A point worthy of note is that engine-room temperatures are usually above the outside shade temperatures in any locality, except where special building designs and ventilation are employed. On this additional score it seems advisable that the reference air temperature should be raised above 35° C.

Non-corrodible brush-gear and damp-proof insulation are features which are not merely desirable but absolutely necessary for many situations.

Much has yet to be done in Australia in the direction of introducing more equitable General Conditions, such as those formulated by the Institution, and it will probably be many years before such Conditions will be in general use here.

#### INSTALLATION AND MAINTENANCE OF PLANT.

The conditions affecting the installation of plant in Australasia are at times unique. The purchasers may elect to erect the plant altogether at their own responsibility and cost; the contractor may provide supervision, or supervision and skilled labour only; or the whole of the supervision and skilled and rough labour may be provided by the contractor. Again, especially in the case of smaller installation work, a separate contract may be entered into with another contractor for the erection.

A point of great importance in connection with any machine which has been sent overseas is the condition of its insulation before setting to work. This is not sufficiently appreciated in the majority of small installations, and especially in cases where the purchaser carries out the erection. A great number of the machines which come to Australasia suffer a considerable change in the condition of their insulation, and although this may not permanently alter the good qualities of the insulation it is always essen-

tial that thorough investigation should be made before the machines are put into service. Insulation-resistance tests frequently indicate a "dead" earth when taken immediately machines are unpacked. This may be due to pockets of moisture or to a general dampness of the insulation, or even to "sweating" over the face of a terminal plate. The trouble can usually be overcome fairly easily by drying out in an oven or by passing current through the windings in the most convenient way. Very stubborn cases are met with now and again, but unless some permanent injury has been done to the insulation, they will usually yield to proper treatment.

Coils with "damp-proof" insulation have been found, after long sea voyages, to be so full of moisture that when the outer insulation was cut or unwrapped, the moisture actually dripped from between the turns. With such a type of insulation it is possible to obtain high resistance readings to earth or between different windings even when the insulation between turns might be extremely low. This type of insulation presents greater difficulty in "drying-out."

The packing of machines in zinc-lined cases for overseas transport is a costly method and really defeats its object. Machines so packed and received in this part of the world show a greater percentage of very low insulation-resistance values than do machines which come out in ordinary cases provided with ventilation holes covered by wire gauze and lined throughout with tarboard. The zinc linings add to the "sweating" which always occurs to some extent, and as they are hermetically sealed this does not improve the condition of the insulation. The ventilated, tarboard-lined cases, on the other hand, allow any deposited moisture to be carried off more or less rapidly and they produce better results at lower cost.

#### TRAINING FACILITIES IN AUSTRALASIA.

It is of interest to note that the courses provided by the universities, colleges, technical schools, and schools of mines, cater not only for those who enter the broad field of electrical engineering with the hope of attaining eminence in the profession, but also for the mechanic,

wireman, etc. The country needs the latter as much as the highly trained technical man.

As Australia and New Zealand are not electrical manufacturing countries there is no demand for the machine designer, or for the machine-assembly and testhouse workmen. Winders are required in small numbers to cope with the repair work which always has to be carried out, and this repair work involves a small amount of machine work as well. Although actual design calculations are not required it is of course necessary for those who have to deal with electrical machinery, either commercially or in operating work, to be acquainted with general machine-design characteristics. A knowledge of the general layout of generating plant, mains, sub-station equipment and distribution networks, as well as of application engineering, embracing the necessary acquaintance with various manufacturing processes, is more frequently required by commercial engineers. This is naturally the case in a country where the commercial engineer has to deal almost solely with the sale of plant and with its operation. He must, however, know the fundamental principles of the design of the machine which he sells, as he frequently has to give advice and information and has not time to refer questions to the works in most cases. Operating engineers must have very similar knowledge, coupled with more particular knowledge of the industry concerned.

The field of the consulting engineer on the other hand embraces both that of the commercial and that of the operating engineers. The work of the consulting engineer calls for a long and broad experience; especially broad in countries like those in question, where the conditions are such that a man cannot often afford to specialize on one particular process or type of plant.

The training facilities in Australasia are sufficient to provide thorough technical and fairly good practical training for the engineers and artisans that are required. The practical training provided by any university or college course is always largely supplemented by that obtained in the earlier years of actual work; and with the rapid growth of electrical undertakings throughout Australasia the facilities for good practical experience are daily increasing.

## PROCEEDINGS OF THE INSTITUTION.

## 586TH ORDINARY MEETING, 10 FEBRUARY, 1916.

Mr. C. P. SPARKS, President, took the chair at 8 p.m.

The minutes of the Ordinary Meeting held on 20 January, 1916, were taken as read, and were confirmed.

The following donations were announced as having been received, and the thanks of the meeting were accorded to the donors :—

*Benevolent Fund:* G. F. Allom, S. Beeton, The Cape Town Local Centre, R. A. Chattock, W. Church, F. W. Clements, W. C. Clinton, V. K. Cornish, The Hon. E. Cozens-Hardy, I. S. Dalgleish, J. D. Dallas, F. R. Davenport, B. Davies, F. E. Davies, M. Deacon, Sir A. Denny, Bart., J. Devonshire, B. M. Drake, Dr. C. V. Drysdale, K. W. E. Edgecombe, W. V. Edwards, S. Evershed, E. Garcke, Dr. R. T. Glazebrook, C.B., F.R.S., G. F. C. Gordon, F. E. Gripper, C. W. Gwyther, H. T. Harrison, C. C. Hawkins, W. C. C. Hawtayne, K. Hedges, J. S. Highfield, H. C. Holroyd, S. Insull, E. S. Jacob, Dr. G. Kapp, A. C. Kelly, W. T. Kerr, J. E. Kingsbury, A. E. Lewin, W. Mead, J. W. Meares, L. B. Miller, W. M. Mordey, W. C. Mountain, Colonel A. M. Ogilvie, C.B.,

C. Oliver, The Hon. Sir C. A. Parsons, K.C.B., F.R.S., W. H. Patchell, C. C. Paterson, F. G. Payne, W. Pintner, A. H. Preece, L. Preece, N. Prentice, T. Rich, E. S. Ritter, R. Robertson, S. R. Roget, S. A. Russell, E. Seddon, J. F. Shipley, A. Siemens, S. Simpson, Sir John Snell, C. Stewart, A. J. Stubbs, W. C. P. Tapper, E. E. Tasker, C. H. R. Thorn, A. P. Trotter, W. B. Woodhouse, J. H. Woodward, and H. E. Yerbury.

*Building Fund:* Professor J. T. Morris, and E. S. Ritter.

The President informed the meeting that, as soon as the approval of the Board of Trade was obtained, a Special General Meeting of Corporate Members would be called for the purpose of approving an addition to Article 41 of the Articles of Association to provide for the expulsion of enemy members from the Institution.

A paper by Mr. O. L. Record, Associate Member, entitled "The Testing of Underground Cables with Continuous Current," was read and discussed, and the meeting adjourned at 9.40 p.m.

## 587TH ORDINARY MEETING, 17 FEBRUARY, 1916.

Mr. C. P. SPARKS, President, took the chair at 8 p.m.

The minutes of the Ordinary Meeting held on 10 February, 1916, were taken as read, and were confirmed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and it was ordered to be suspended in the Hall.

Dr. C. Chree, F.R.S., delivered the Seventh Kelvin

Lecture, entitled "Lord Kelvin and Terrestrial Magnetism" (see page 405).

A Vote of Thanks to the Lecturer was proposed by Dr. A. Russell and seconded by Mr. Roger T. Smith, and was carried with acclamation.

The meeting adjourned at 9.45 p.m.

## SPECIAL GENERAL MEETING OF CORPORATE MEMBERS, 1 MARCH, 1916.

Mr. C. P. SPARKS, President, took the chair at 5 p.m.

The Secretary read the Notice convening the Meeting.

Mr. Sparks. The PRESIDENT: The question known to the man in the street as "the alien enemy question" has been before the Council on several occasions. Attention has been called in the *Journal* to the fact that we have certain powers under Article 41, including ample power to deal with any undesirable member, but no action under this Article has been taken by individual members. Subsequently, the Council appointed a Committee of the Vice-Presidents to report on this matter. When the Committee met, they had also before them a petition signed by 17 members of the Institution, calling upon the Council to take action on certain lines. Their proposal was considered; and as the result of a conference between myself and a number of representatives of the signatories to the petition, a form of words was agreed upon, which is before the meeting

to-night. I propose to call upon Mr. Baker, who is one of Mr. S. the 17 members I have just referred to, to second the resolution, and after that any member who wishes to do so may speak on the subject. Legal opinion has been taken with regard to the procedure at this meeting. Generally speaking, amendments cannot be accepted, because under Article 81 no other business can be transacted except the business specified in the notice convening the meeting. I now propose the following resolution :—

"That the following words be added to Article 41 of the Articles of Association, namely :—

(a) In the event of a state of war arising between the United Kingdom of Great Britain and Ireland and any other Country or State, any member of any class who at any time during such war shall be a subject of such enemy Country or State shall forthwith cease to be a

member of the Institution, and in the case of the European War of 1914, all such members shall cease to be members of the Institution on and after the 16th day of March, 1916."

Mr. C. A. BAKER: I have much pleasure in seconding the resolution. For a long time members have felt that something ought to be done in this matter, but it was not until the 15th December last that a short paragraph appeared in the *Journal* of the Institution. That paragraph was very disappointing; it told us the Council had no powers except those under Article 41. In consequence, I wrote a letter which was published in one of the electrical papers on the 31st December, 1915, and as a result of that letter it was suggested to me that I should go a step further and present a petition. I had no difficulty whatever in getting the 17 signatures which the President has mentioned as the number of members who signed that petition: it was handed in on the 18th January. On the 21st January, at the invitation of the President, some of the signatories conferred with him and he put before us three or four alternative proposals for a new Article, among them one which was, I understood, on the lines of the resolution that had been adopted by the Iron and Steel Institute; we all of us felt that we could accept it. The petition did not deal with naturalized aliens, as they have a status in this country and are amenable to the laws in the same way that we all are. If, however, this resolution is passed I understand that naturalized aliens will be expelled if they have not de-naturalized themselves in their own country, and I shall be glad if the President will definitely state this to be the correct interpretation.

Mr. A. GAY: In a letter which I sent to the President a day or two ago, I asked some questions with regard to procedure, and I shall be very glad if he will reply to them.

(The President then read Mr. Gay's letter and in reply stated that he did not propose to put to the meeting the question of whether the voting on the resolution should be by ballot. He also stated that the amendments proposed by Mr. Gay were not in order, as it would be necessary for 14 days' notice to be given before the matters dealt with could be put to the meeting.)

Mr. L. JOSEPH: I thoroughly agree with the resolution, but there are one or two things that are not clear in regard to the results. Can a member who is now expelled be re-elected at the end of the war? I think the feeling of the meeting is not only that he should be turned out for the period of the war, but that he should be exiled permanently from the Institution, and that no one of his nationality should hereafter be elected as member.

Mr. A. H. WALTON: With regard to naturalized alien enemies, it seems to be that if we have a law in this country which gives a man naturalization, it is not for us to turn round and say we are going to do something else. On the other hand, there are two kinds of aliens, namely, de-naturalized and naturalized. We have some good friends in the Institution who are aliens and who are naturalized. Speaking boldly, I would sooner court those men's friendship than I would that of those who allow Germans to come here and exploit us. I consider it would be a very great injustice to those men, after they have belonged to the Institution for so many years, to expel them on the ground that they happen to be alien enemy members. It

would, however, perhaps be advisable to call upon those of our alien members who have been naturalized to produce proof of their having renounced their country of origin.

Mr. C. C. ATCHISON: This meeting is supposed to represent the ideas and opinions of the whole of the members, but it is not fairly representative. Whatever action is taken, such action should be representative of the wishes of the majority of the members, and I think therefore every member should have an opportunity of recording his vote. By holding this meeting in London, every member is not given such an opportunity. In many ways I am very much in favour of the resolution, but in my opinion it does not go far enough, as it does not state what will be the position of the alien enemies at the end of the war. Are they to come back and sit at meetings of the Institution shoulder to shoulder with members who have had to fight against their ghastly deeds at the Front or those whose families are suffering from the loss of dear ones killed in the war? Are they to sit alongside those whose friends or relatives have been wounded or killed by their Zeppelin raids, or by bombardments such as that at Scarborough?

THE PRESIDENT: I should like to point out to Mr. Atchison that it is entirely in the hands of our own members whether these people are ever re-admitted to membership. Speaking for myself as a Corporate Member, I am not going to have them back, but I am one only. None of them can come back unless we, i.e. the members, re-elect them. The onus is on members to see that these men do not come back.

Mr. ATCHISON: What I wish to emphasize is that the ordinary member it is not clear that it is intended to exclude Germans from the Institution after the war. The President states that it is going to be left to the members to say whether Germans will be taken back or not, but as all applications for membership are first submitted to the Council, and subsequently for ballot only by members present at the meetings in London, that does not give the whole body of the members an opportunity of saying whether they will have Germans back or not. I think it is only fair where we are dealing with a problem of this sort, which is one that many of us feel very strongly upon, that it should be possible for every member to say whether he wishes to have Germans associated with him in the Institution. In fact, I know that there are a large number who will cease to be members if Germans are re-admitted.

Mr. A. GAY: I wish to ask the President whether he can accept the following amendment: "That the meeting be adjourned, and that a vote be taken by ballot of the whole of the Corporate Members of the Institution, by post, both upon the principal motion and also upon the amendment." If that amendment cannot be accepted, will it be in order if it finishes at the words "principal motion"? (The President stated that proper notice would have to be given before the amendment could be considered. Mr. Gay then moved the adjournment of the meeting for that purpose, and on the President's refusal to accept that motion, Mr. Gay protested that the proceedings were irregular.)

Mr. F. C. RAPHAEL: May I intervene for a moment, because I think perhaps Mr. Gay will be satisfied with the

Mr. Raphael.

suggestion that I should like to make. First of all I wish it to be understood that I—as probably most of those here do—cordially support the resolution before the meeting. As the President has made up his mind to put this resolution to the meeting, and as probably everybody in the room agrees with it, although some would like it to go much further, it would be a great pity if that resolution were not carried in this meeting with absolute unanimity. I suggest, therefore, that the resolution should be allowed to pass unanimously, and that, subsequently, Mr. Gay and others who wish to should hand in their resolutions under Article 80 with a request for another Special General Meeting to consider such resolutions. The Council's resolution and any other resolutions could then be brought before the same confirmatory meeting. That is to say the proposed confirmatory meeting should be deferred until the other resolutions have been considered or passed.

Mr. Sparks.

The PRESIDENT: I am much obliged to Mr. Raphael for his suggestion. I understand from the Honorary Solicitor that the course proposed is in order, but I should like to mention that the Institution is incorporated under the Companies Act, and that but for the licence granted by the Board of Trade it would be compelled to use the word "Limited" as part of its name. The Board of Trade require, as a condition of such licence being continued, that any proposed alteration in the Articles of the Institution shall be submitted to and approved by the Board of Trade before it is made. We have submitted this resolution to the Board of Trade, and we have their approval. Any further alterations proposed would have to be submitted to the Board of Trade for their approval.

Mr. Gay.

Mr. A. GAY: Mr. Raphael's suggestion would, I think, remove many of our objections if the President would agree to it, but a difficulty arises, as the second meeting has been fixed for the 16th March.

Mr. Sparks.

The PRESIDENT: If we pass this resolution this afternoon, and then I receive a proper notice with regard to further resolutions, I will undertake to adjourn the proposed confirmatory meeting until the other matters can be considered at the same time.

Mr. Berkeley.

Mr. A. BERKELEY: I should like to take this opportunity of heartily endorsing what Mr. Atchison has said. I for one, at any rate, believed, when I received the notice of this meeting, that we were not coming here merely to say "yes" or "no" to this resolution, but that we should have the opportunity of thoroughly discussing the question of alien enemies and naturalized Germans. It seems to me we ought to take a certain amount of risk. Let us put the onus on the other side. Let those who object to these amendments, who want to see the Germans and naturalized Germans back in the Institution, come forward and raise the legal technicalities, and let us fight them on it. This is war time, and we have a terrible, cruel, and wicked enemy, and we ought to deal with him accordingly and not allow ourselves to be fettered by any legal technicalities.

Mr. Woodhouse.

Mr. W. B. WOODHOUSE: I should like to say that I am going to vote for this resolution because I think it covers the ground as well as any resolution can, but I am going to vote for it on the understanding that any naturalized alien enemy who has not taken the trouble to get rid of his nationality in an enemy country is automatically

removed from membership by this resolution. I think we must look forward also to what will happen after the war. If we go so far as to exclude all our present enemies for ever without having an opportunity of reconsidering our decision, I think we may afterwards regret it.

Mr. E. MACGREGOR DUNCAN: I believe when the history of the Institution during this war comes to be considered some years hence, perhaps the Institution as a whole will feel it owes some slight debt of gratitude to any members who have had the pluck to come here and oppose this resolution. One runs the risk of being called pro-German, but that cannot be helped. I believe this to be one of the most important matters that has ever been brought before the Institution—the question of excluding a considerable number of members in a body. I feel that the only way in which we should ever exclude members should be personally, by taking each member in question, considering his behaviour, and then deciding whether he is fit or not to belong to the Institution. I believe the London Stock Exchange, which has always been noted for its extreme patriotism, and which consists largely of a body of sportsmen, have considered this matter most fully and have decided that enemy members be requested to refrain from attending. I believe this matter has also been considered very fully by the Institutions of Civil and Mechanical Engineers, and these bodies have decided to do nothing. The only other remark I want to make is that we have heard a great deal to-day about Germans and about our German enemies. If this resolution dealt with Germans I should not object to it to the extent I do, but it seems to me we are not quite honest. We mean Germans all the time.

The PRESIDENT: Mr. Baker has asked a difficult question with regard to the position of the naturalized alien. In the resolution we have these words, "shall be a subject of such enemy Country or State." This is really a question of law. If in this country we give a man a naturalization certificate thereby accepting him as a British subject, does our law prevail over the law of other countries? As I understand the matter, he will not be automatically struck off the Institution Register if he has naturalization papers. Still, under Article 41, any 10 members can cite any particular naturalized person (or persons), and, if he is undesirable, we can get rid of him. That is to say, we have to deal with those cases either individually or collectively, but we do not get rid of them automatically if this resolution is carried to-day. The next question is: Can a member now turned out be re-elected? I have already dealt with that. It is in the hands of every one of us, and it is the business of every one of us to see that they are not re-elected. (Mr. JOSEPH having handed in an amendment to the resolution, the President said that he could not accept it.)

Mr. A. A. C. SWINTON: Before the resolution is put I should like to say that I was one of the 17 members who signed the petition, and I am afraid the President's interpretation of the proposed addition to Article 41, that it will not exclude Germans who still remain German subjects though they have become naturalized Englishmen, puts a very different complexion upon the resolution from what I expected. Speaking for myself, it is not satisfactory to me, and I doubt if it is satisfactory to the other 16 members.

Mr. W. B. WOODHOUSE: I also do not follow the interpretation which has been given by the President, and if it is the legal interpretation I shall vote against the resolution.

Mr. E. J. FOX: If an alien is not de-naturalized he is obviously a member of such enemy country, and therefore this resolution does not convey the meaning which the President expressed on the point.

The HONORARY SOLICITOR: If any individual has been naturalized, I think our Courts look on him as an Englishman. They do not care how Germany regards him.

Mr. FOX: I think that is quite possible from a legal point of view; in fact, I think that point has been decided in our Courts. But this is a clause in our own Articles, and here we specifically say, "shall be a subject of such enemy Country." If he has not been de-naturalized he is a subject of such enemy country. If I may say so, the President's explanation is contradictory to the meaning conveyed in plain English by this resolution.

Mr. G. W. PARTRIDGE: I agree with what has been said by the last speaker. In my opinion, so long as an alien enemy is a subject of a country at war with this country, he most certainly comes under this clause and would be automatically expelled.

Mr. A. A. C. SWINTON: I think there is a misunderstanding. According to my belief, a man can be a subject of Great Britain under British law and at the same time a subject of Germany under German law. It depends upon which Court he goes to. I take it that our Articles would be interpreted in this country under British law, and that therefore the President's explanation is quite correct, namely, that the resolution would not exclude naturalized Germans who still remain Germans according to German law. That is, however, not what I want, and I do not think it on him the other 16 signatories to the petition intended.

The PRESIDENT: This resolution was drawn up by the Council and approved, and I am advised by the Honorary Solicitor that that is its meaning according to law.

Mr. L. B. ATKINSON: Apparently we are at variance over the wording of the resolution. I would suggest that if instead of saying "during such war shall be a subject of such enemy Country" we were to say "during such war has not divested himself of his nationality of such enemy Country," it would cover our Honorary Solicitor's point. It does not alter the sense of the resolution.

The PRESIDENT: I regret to say that the Honorary Solicitor informs me that I cannot accept that amendment.

Mr. W. R. COOPER: It is not of much use to pass a resolution which we do not understand. The difficulty of the whole matter is that most of the members are ignorant of Company Law. Is it not possible to adjourn this meeting and call it again later on, with a proper notice, and then for the various amendments to be considered at the same time, proper notice of them having been given?

Mr. J. H. RIDER: After the President's explanation of the meaning of the Resolution, I feel bound to vote against it, and I hope all the other members will. Let us then have a clear resolution which we all understand, brought up at the proper time.

Mr. L. L. ROBINSON: I want to know if I would be in order in moving that this resolution be referred back

to the Council for further consideration, and whether, if that were done, the Council could then put forward a resolution in a form in which it could be discussed and, if necessary, amended by the Corporate members of the Institution.

The PRESIDENT: The Honorary Solicitor informs me that the only way in which we can have an informal discussion is to call another meeting for that purpose to discuss the matter in all its bearings. Then if a majority of those present determine on any form of words, we could give 14 days' notice to call a Special General Meeting, hold that meeting, and follow it by a confirmatory meeting. That will give facilities for every member stating his views and bringing up any amendment he likes.

Mr. T. PETERSEN: The President's explanation has answered the question I intended to ask. I was going to suggest that the best method would be to call an informal meeting to discuss, without any form of words or resolution, whether it would be advisable to expel alien enemies; and, after the meeting has been held, to draw up a form of words and call a meeting to pass them.

Mr. F. C. RAPHAEL: I would remind the meeting that only a few years ago on the occasion of a similar Special General Meeting for the alteration of the Articles of Association, there was strong opposition to the Council's original proposals, and that the Council then adjourned the meeting, and held a number of informal meetings at which the matter was fully discussed. Subsequently new Articles were drawn up and they were passed almost unanimously. In view of the ambiguity as to the meaning of the resolution before us to-day, I should like to propose that we have an informal discussion such as the President has suggested.

A MEMBER: May I suggest that words should be added to the effect that alien enemies shall not be allowed afterwards to enter the Institution until a vote has been taken of the whole of the members of the Institution. What we all have in our minds is that it would be very awkward, after this war is over, if the Germans came in one at a time.

The PRESIDENT: That could be discussed at the same time. I have decided not to put the resolution. I shall call an informal meeting to discuss the whole question, and the Council will be very glad to receive suggestions from the members.

(A vote of thanks to the President and Members of Council was proposed by Mr. W. L. Madgen, and seconded by Mr. A. Gay, and was carried with acclamation.)

The PRESIDENT: It is a matter of great difficulty to conduct a meeting of this kind, and I must thank members very much for the way in which they have helped me. I have endeavoured to be fair and impartial. There is no wish either on my part or on the part of the Council to restrict debate or not to arrive at the best possible solution of the question. I am sorry for the country members who will have to come to town again, but the matter is one of special importance.

Mr. C. C. ARCHISON: I should like to say, on behalf of those country members who cannot get up to town, that there should be some means of their knowing what is taking place.

The PRESIDENT: I shall try and do that. The meeting adjourned at 6.40 p.m.

## INFORMAL MEETING OF CORPORATE MEMBERS, 8 MARCH, 1916.

Mr. C. P. SPARKS, President, took the chair at 5 p.m.

Mr. Sparks. THE PRESIDENT: At this meeting we cannot alter the Articles of Association, because, before we can do that, it is necessary to give 14 days' clear notice to members and then to have a confirmatory meeting; but we can try to arrive at a form of words which, when approved by the Board of Trade and sent out after 14 days' notice, can meet with the approval of the majority—it has to be a three-quarters majority—of those present at the Special General Meeting when called. The Council have agreed to adopt a suggestion that has been made, namely, that before a Special General Meeting is called the views of the members as a whole shall be ascertained on the one or more resolutions that may be determined upon to-night. (The President then read a number of letters which had been received.) It may save the time of the meeting if I say there appear to be three classes to which we ought to direct attention. First, there are the subjects of an enemy country. There is no question that they were dealt with fully in the notice of the meeting for the 1st March. Those in the second category are naturalized British subjects who retain enemy nationality. Many members felt that the notice of that meeting dealt with such persons, but our legal adviser informed us that there was considerable doubt on the matter. The third class includes naturalized British subjects who were formerly subjects of a State now at war with Great Britain and Ireland but who have definitely lost their alien nationality.

Colonel Crompton. Colonel R. E. B. CROMPTON: I am familiar with this subject, having served on Committees of the Royal Automobile Club and heard most of the arguments for and against the expulsion or retention of those who may be considered by birth or extraction as alien enemies. In my opinion a matter of principle arises quite apart from this question. Feeling strongly as I do that Members of Council should judge of each case on its merits, I take strong exception to the proposal that is now before us, which would appear to take away from the Council all discriminating power. The question really amounts to this: Are the members of the Institution prepared to take away from their Council the powers which ought to be vested in the Council of every scientific body? Such a proposal is, to my mind, a sign of either decadence of the Institution itself or a want of confidence in their Council. I do not like to see electrical engineers show signs of hysteria, and it does appear to me that if we agree to this resolution to take away from the Council all option of exercising their judgment in such a matter as this, we show signs of hysteria of which I am ashamed. As English electrical engineers and as Englishmen, we pride ourselves on level-headedness. We are proud of doing the right thing—the fair thing—the just thing—we are not afraid of anybody in the world and I hope we never shall be. This demand to take away free action from the Council by compelling them to expel every member whose family for generations back has been connected with Germany or other alien enemy nations, does savour of timidity. I should be very sorry that future generations of electrical men should say that we English electrical engineers, at this critical period of our history, should show these signs of hysteria and timidity.

Mr. J. S. HIGHFIELD: I want to consider first of all what powers the Council have in this matter of the expulsion of members. The Council at the present time on their own initiative can expel felons or bankrupts or people who are criminals. They cannot expel an enemy of this country. My opinion is that we ought to have that power. The next point is that we have a certain number of members who are naturalized subjects of this country; and many of them have sons and relations actually fighting for the country at the present time. My own view is that men of that class, bona-fide British subjects by the laws of this country, should be treated as other British subjects, and that we should have no right, even if we could acquire the power—in which I am not at all sure—to turn out such men. In the German naturalization law of 1913, however, there is a curious point. The old German naturalization law provided that if a German subject left his country and went to live in a foreign country and lived there continuously for 10 years he automatically ceased to be a German. The new law is to this effect, that a German who leaves his own country and goes to reside in a foreign country does not automatically lose his German nationality; on the other hand, he retains it; but if he should choose, of his own volition and at his own request, to become a subject of the country of his residence, then he automatically ceases to be a German subject. If, however, a German comes to reside here, and for business purposes it suits him to become a naturalized subject of this country, he may by the new German law of 1913 apply to the German Government to retain his German nationality before he applies for naturalization papers here. In that case he is a subject of both countries. Now it seems to me that that kind of naturalized subject is quite the worst kind, and I think the Council ought to have powers to expel such a man, just as it ought to have powers to turn out the actual enemies of the country. I must say I very much agree with Colonel Crompton in not liking to take out of the hands of the Council a power that they have at the present time. At the present time any 10 members of the Institution can turn out any person they think undesirable by signing a requisition, and I think, if they put forward to the Council at the present time the name of an actual enemy, that would be a sufficient reason for that particular member being expelled. Now, if we were to pass the resolution proposed last week, we should take out of the hands of the Council the power of dealing at their discretion with the above two classes of people—the peculiar form of naturalized subject and the active enemy, and I should like to retain that power for this reason. I believe we have one or two Armenian members, who are consequently Turkish subjects. Now I do not think any one of us wants to turn those people out, and yet if we pass that resolution they would automatically have to be expelled. I wish to retain full freedom of action. I should therefore like to add words to Article 41 to this effect, "that in the case of any member of any class being the subject of an enemy State or being a naturalized British subject who is of his own volition also the subject of a foreign State, the Council may, without any such proposal or steps being taken as have been stated, remove his name from the register of the Institution." Those words would

enable the Council not only to expel or remove from the register the name of an actual enemy subject in war time or at any time, but also to remove in peace time enemies of this peculiar type of naturalized subjects to whom I have referred. This addition would automatically prevent such men being elected as members.

Mr. J. H. RIDER: I should like to read a memorandum which has been prepared by my friend Sir John Snell, who unfortunately is unable to be here to-night:

“SIR JOHN SNELL: I think it is clearly just that those of our members who happen to have been born in an enemy country but who have taken out naturalization papers here and have become British citizens (provided they have not requested the country of their birth also to retain them as citizens), that is, if they are clearly British citizens, should remain on the Roll of this Institution. Members who are not British citizens and are still enemy aliens—even if only technically so—would have to be removed. I am also very emphatically of opinion that, after the war, we should not elect into our Institution any persons who are citizens of our present enemy countries. So long, however, as a naturalized British subject is faithful to his oath of allegiance to the King and to the laws of this country, I do not think he should be removed from the List of Members, subject to the reservation above.”

Mr. RIDER: I should have been prepared at the last meeting to have supported the resolution as it had been drafted by the Council, if the literal meaning of certain words in the resolution had been adhered to, or if the President had ruled that they would have been so literally construed. I refer to the words “shall be a subject of such enemy Country or State.” All that is required is, I think, that the resolution as framed by the Council should be extended sufficiently to make it absolutely clear without any shadow of doubt what we are driving at. I think my intentions and meaning will be perfectly clear if I merely read my resolution, which is as follows:—“That the following words be added to Article 41 of the Articles of Association, namely: (a) In the event of a state of war arising between the United Kingdom of Great Britain and Ireland and any other Country or State, any member of any class who at any time during such war shall be a subject of such enemy Country or State shall forthwith cease to be a member of the Institution. (b) No person shall after the . . . day of . . . 1916 be eligible for election as a member of the Institution who is a subject of any Country or State with which the United Kingdom of Great Britain and Ireland is or shall have been at war on or after the date mentioned. (c) The words ‘a subject of such enemy Country or State’ in (a), and the corresponding words in (b), shall include all persons who have taken out naturalization papers in the United Kingdom of Great Britain and Ireland, but who remain subjects of any enemy Country or State under the laws of such Country or State. (d) The onus of proof that he is not a subject of any enemy Country or State shall lie with the member or person desirous of being elected a member of the Institution, and until such member or person individually shall have produced proof of his having ceased to be such a subject to the satisfaction of the Council of the Institution he shall cease to be a member or shall be ineligible for election as a member, as the case may be.

(e) In the case of the European War of 1914 all such members shall cease to be members of the Institution on and after the . . . day of . . . 1916.”

Mr. C. H. WORDINGHAM: The first point I wish to make is that we must approach this subject from the point of view of our own Institution. It is for us to say whether we choose to have people in our Institution whom some of us condemn and abhor. I have no doubt whatever as to the propriety and justification for excluding all Germans from the Institution, and in my opinion such exclusion should be for such time as is necessary for the present generation of Germans to die out. It will be noticed that I rather insist on the word “German.” Rules for the exclusion of alien enemies would obviously apply to all those nations which are at war with this country, but I do not class the other enemy nations in the same category as the Germans. As regards naturalized Germans, the matter is admittedly extremely difficult. I have given very anxious attention to the matter myself, and I admit there are very serious difficulties. There can be no doubt that some naturalized Germans are English in their sentiments and in their aspirations, and that they are thoroughly loyal. They have sons fighting in the service of this country, and undoubtedly such naturalized Germans as those ought to rank as Englishmen. But there are a great many who do not come into that category. Personally, I do not care very much whether the naturalized German has been de-naturalized in his own country or not. To me it is most significant that the German law allows a German-born man to become naturalized in a foreign country and also to retain his German nationality. In my opinion many of the naturalized Germans in this country are infinitely more dangerous than the avowed Germans who have not been naturalized. It is difficult to deal with these men; for how is the Council to know whether a particular naturalized German is or is not a traitor to his adopted country? There are two general observations which I will make without comment on naturalized Germans, and they are these. Usually a man becomes naturalized in a country in which he is not born for purposes of gain. Do we think very much of the loyalty of such men? Secondly, most naturalized Germans are, I think, very closely connected with concerns that have very strong connections in Germany. In dealing with this question I think we must not be too careful of hurting innocent people. It may be necessary, in order to exclude the dangerous naturalized subject, to exclude also the subject who is naturalized and who has really become to all intents and purposes an Englishman. Finally, I wish to disclaim altogether any feeling of hysteria in the matter; my feelings are the deeply rooted growth of years and long ante-date the war.

Mr. W. RUTHERFORD: I want to deal with this subject on broad principles. I am entirely in sympathy with the expulsion of enemy aliens, but I am not in sympathy with the suggestion that naturalized enemies should be dealt with in the same way. There are naturalized German-born members of the Institution who have belonged to it for 15, 20, or more years, who have lived here all the time, who have been connected with the industry of this country and have done good work for it. Another point is, how are we to compare these men with what I might call neutral enemies? There are no doubt a number of members of the Institution—Danes, Swedes, Dutchmen,

Mr. Rutherford. and Swiss—who are working in Germany to-day, using their brains and their hands in building armaments to fight us. Why not deal with them on the same footing? (A MEMBER: They have not committed atrocities.) What is the legal aspect of some of the suggestions that have been made to-night? A German or an Austrian, if he becomes naturalized in this country, becomes a British subject, and it is one of our proud boasts in regard to any Englishman that, whatever accusation is made against him, he is innocent until he is proved guilty. I think the problem of naturalized aliens should be left in the hands of the Government.

(Mr. A. GAY asked the President whether he would agree to ascertain the feeling of the meeting by means of a ballot upon the various proposals that might be made. The President replied that, in the case of the present meeting, if at a later stage he found that the majority of those present wished to have a ballot he would not oppose it.)

Mr. Gay. Mr. A. GAY: I beg to move formally the resolution which I have handed in, namely, to add after the word "State" in the fourth line of the original resolution of the Council the words "or shall be of enemy origin, although a naturalized subject of the British Empire." The resolution of the Council would, I think, have been quite inoperative; first, because all Germans in this country are either interned or else fighting in Germany, and secondly because it did not include naturalized British subjects in England who are still subjects of the Kaiser. I agree with Mr. Wordingham that naturalized aliens are often far more dangerous than the non-naturalized ones, since in many cases they are purely spies. Mr. Wordingham raised a very important point when he said, how are we to be certain that a naturalized British subject has been de-naturalized in his own country? A great deal has been said to the effect that it would be an injustice to turn the naturalized aliens out of the Institution. Can we compare, however, the trifling injustice, if there is any, of such action with the injustices and atrocities that have been perpetrated by this nation of so-called men? The most that any member of the Institution can suffer by being expelled in this way is a very slight loss of prestige.

Mr. Madgen. Mr. W. L. MADGEN: If any country has benefited by immigration it has been this country. Mr. Wordingham said that when a foreigner came over here he generally did so for his own advantage, but surely history is punctuated with cases in which the suffering population of other countries has found asylum here and we have benefited by it. I need only remind members of the Huguenots who came over and assisted us in the establishment of the linen, the silk, and other industries, and of the Dutch, who came and settled in Yorkshire and Lincolnshire and helped to reclaim large pieces of the country. There are no less than 13 million Germans in the United States, a large proportion of whom have fled from the plague of militarism from which Germany is now suffering, and I believe that on the whole this country has benefited by the migration of Germans here. In connection with Mr. Highfield's remarks, I should like to emphasize the point that it is under the German law of 1913, which became operative on the 1st January, 1914, that, when a man wishes to be naturalized abroad, he can elect whether he will give up his German nationality entirely or whether he will have a double nationality, so to speak. It does not apply

to those who were naturalized before that date, and who therefore were no longer German citizens. I should like to second Mr. Rider's resolution, but in doing so perhaps I may point out that it might have been put more concisely; thus the following words inserted in the resolution which was before the last meeting will be seen to be sufficient: "or having been born the subject of such enemy Country or State has not completely divested himself of such nationality."

Mr. L. B. ATKINSON: In reference to Colonel Crompton's remarks, it is not a question of whether we are afraid of Germans, but of whether we choose to allow people who have the characteristics that have been described to us to-night to associate with us and, as we well know, make all the use of us they can for their own purposes. I do not think it is really a question of whether we have confidence in the Council or not. Some of us had perhaps begun to lose confidence in the Council, because they had not acted, until we realized that they really could not act unless we did something and urged them up to the point; they had in fact not got the powers to act themselves. With regard to the criticism of the Council by Mr. Gay and others, the Council had before them a request from 17 members to take action in this matter; they did not know how many members wanted to take action, but they assumed that those who had taken the trouble to move were the people interested or represented them, and they invited them to come and discuss the matter. The resolution that was put before the last meeting was arrived at after discussion with those who took the trouble to interest themselves in the matter, and was a resolution which the Council thought would meet their views. It is perfectly true that they tripped up over the meaning of a word, but I do not think we can blame the Council for not having consulted the members, since they did consult those members who had shown an interest in the matter. I want to make a suggestion to enable us to get on a little faster with this meeting. First of all we should settle whether we are going to ballot or to hold up our hands. Personally I cannot imagine why we should go through the lengthy process Mr. Gay advocated. Next we must determine, without going into details, whether we want to expel both naturalized and unnaturalized members, or merely those who are still in some way attached to their old nationality; and having determined these broad questions we can proceed to discuss some details to carry them out. I personally am prepared to take some risks in retaining in the Institution these aliens of enemy origin who have naturalized themselves and who are properly de-naturalized in connection with their own country. Indeed, I should not mind if a few slipped through the mesh, because our object in this action is more of a moral one than actually to get hold of every enemy alien. We want it to be known that the Institution announces as a principle that it will not accept fellowship with individuals who owe allegiance to States who have cast to the wind every code of honour, every rule of international law, and all that makes civilization worth having.

Mr. A. A. C. SWINTON: I am of opinion that we ought not to expel a naturalized British member although he is of German origin, provided that he is properly naturalized and retains no allegiance to his country of birth. But certainly I think we ought to expel the non-naturalized

enemies and those who retain any allegiance to their original country. I therefore have much pleasure in supporting Mr. Rider's resolution.

Mr. L. JOSEPH: Mention has been made, by a previous speaker, of neutrals now working against us in Germany. I do not call to mind a single instance; but if such were found to be the case, a special clause should be inserted in the Articles, preventing such members retaining their membership, because they must certainly be considered to be enemies. I have noticed that most speakers have been confining their remarks to the Germans, these being our most powerful opponents—militarily and industrially—whilst they have left unmentioned all our other enemies during this war who are just as bad. It is not only because that they are bad that we want them out, but because as a body of business men we desire to eliminate their competition and take this opportunity of so doing. It is therefore to be hoped that any resolution framed will include the expulsion of members of all nations now warring against us, and that no new members of such nationalities be elected after the war.

Mr. A. BERKELEY: At the last meeting we were dealing with alien enemies in the true meaning of those words. At this meeting we seem to be dealing solely with naturalized German subjects. What we really want to settle is whether a bona-fide naturalized subject is worthy of being retained as a member. I believe that none of us would wish to do any injustice to any member. It seems to me, therefore, there are two alternatives. We can either first expel all Germans, naturalized and un-naturalized, and then find some means of reinstating those that are entitled to be reinstated, for instance, those who have sacrificed their sons for this country; or, on the other hand, we can leave things as they are, so far as naturalized Germans are concerned, and then expel one by one those who we consider should be so dealt with. To get down to practical politics, I think we ought to endeavour to arrive at a conclusion which may be termed a mean between the extremist on one side and the moderate man on the other.

Mr. W. M. MORDEY: May I make a suggestion as to procedure? We all know by experience how difficult it is for a large meeting to settle forms of words to express agreed meanings. I suggest, therefore, that we should try and settle broadly what we want, and then leave it to the Council, or to a Committee appointed by this meeting, to find, with or without the assistance of the Honorary Solicitors, appropriate words to be put later before the general body of members.

Mr. J. C. WIGHAM: Under a sense of duty I wish to protest against the whole procedure now being discussed by the Institution. I think it can only be expressed as "piffling." Do we really imagine that amity amongst the nations of Europe will never be restored? What we all ought to be doing to-day is to work all we can to bring the war to a satisfactory conclusion. Is this afternoon's meeting assisting to do so?

Mr. J. T. IRWIN: The new nationalization laws of Germany are a confession of her weakness, not a proof of her cunning. She was losing citizens, and these were being absorbed into and adding to the strength of other States. We are asked to adopt measures that make Germans ready to renounce their country. We have given

naturalization papers to certain aliens, and we ought certainly to observe the promises contained therein. The only point that can be raised against such members is that perhaps 1 in 100, or in 30, or in 25, may be a traitor, and that this small number of naturalized citizens may do us an injury. Are we afraid of these one or two? It has been said that neutrals may be helping in the manufacture of war materials in Germany. Are we also going to expel such members? I think we should consider a resolution in the following form: "That every member of alien nationality shall be asked to make a declaration that he supports the cause of the Allies." It may be of great advantage to us hereafter to have been broad-minded in this matter.

Mr. F. GILL: I wish to support Mr. Mordey's suggestion, but it seems to me there are two points which want clearing up. First, are we legislating for a specific case or are we laying down a fundamental plan which shall apply to every war? My own feeling is that it ought to be left, as Mr. Highfield said, with the Council to have the power to settle this, and that it is not necessary that it should be automatically done for each and every war. The second point is the very difficult question of the naturalized alien, and it is particularly difficult in the case of what I am going to call the "bi-naturalized alien." But there is a short-cut to the solution. When an alien takes out naturalization papers he gets this promise made to him in his certificate—that he is thereby naturalized as a British subject, and that upon taking the oath of allegiance he shall in the United Kingdom be entitled to all political and other rights, powers, and privileges, and be subject to all obligations to which a natural-born British subject is entitled. It seems to me that is the crux of the matter. I would rather suffer some injury than that we should go down to posterity as a people who are going to tear up an agreement made by their responsible representatives.

Mr. J. E. KINGSBURY: It seems to me that what we want to do is to bring ourselves within the law, not merely in the letter but in the spirit, and to deal with this whole subject recognizing that we are not the State but an Institution established for a scientific purpose. Our rules are determined by law, and our acts should be governed not by something that we may like or think we ought to do, but by the general policy of the State. We have at the present a war in progress which, as Mr. Gill has said, is no ordinary war. We all know what is in our minds when we are dealing with this alien question, and I should like to remind members that the German nation is not a member of this Institution. What we have to deal with are individual members, and three courses are open to us. The President has read a number of letters from influential members who suggest that the proper thing is to do nothing. I hope we shall all remember that when a member suggests we should do nothing, he is considering the interests of the State and of the Institution just as much as those members who desire that we should do a great deal. At the other extreme, we have a suggestion that a resolution should be carried which expels members who are naturalized British subjects. Again I wish to express my cordial agreement with Mr. Gill in thinking that that would obviously be an improper thing to do, especially if we regard it from the point of view that we must do as the law directs we

Mr.  
Kingsbury

shall do, and act as the State decides by custom that we shall act. We have unhappily fallen away from that point of view, and we have consequently got into an argument which permits the expression of opinions which are very credible indeed to the individuals under proper circumstances, but which, I submit, are absolutely irrelevant here. We, as a scientific Institution, determine who are the proper people for us to elect as members and for us to associate with in the Institution. If we are going to expel any members we must take care that those whom we do expel are people that we have the right to expel by law. Between the two extremes which I have referred to there is what I may call a mean in the resolution that was submitted by the Council at the last meeting. Unhappily a difficulty arose in regard to that resolution, in consequence of some misapprehension in regard to its legal application. If the Institution allows itself to get entangled in legal discussions, it will be through its own fault, and if we pass a resolution, I take it that what we shall have to do will be to interpret that resolution according to the English law and according to the customs of the English State. What I would suggest is that the President should ask the meeting (1) Are we going to do nothing? (2) Are we going to expel the German members in accordance with the resolution submitted by the Council, subject to any ordinary modifications? (3) Are we going to try to expel naturalized members?

Mr.  
Partridge.

Mr. G. W. PARTRIDGE: I do not think it is a question for the Council to settle who should be expelled from the Institution, but one that should be settled entirely by the members. With regard to the proposal before the last meeting, I would suggest that after the words "subject of such enemy Country or State" be added "who has not been de-naturalized."

Professor  
Silvanus  
Thompson.

PROFESSOR SILVANUS P. THOMPSON: I wish to associate myself with the views expressed by Mr. Kingsbury and Mr. Mordey. I strongly urge also that we should not treat this question as though the Council were going to have the power taken away from it of exercising its legitimate and rightful discretion in individual cases. By condemning men *en bloc*, we might do a very great injustice. The Council must be left with powers to discriminate, owing to the extraordinary difficulties that arise in connection with the definitions of an alien enemy and of a naturalized alien. The number of classes are really not three, as has been suggested, but more like fifteen. In the first place there are the actual alien subjects of enemy nations living abroad in their own countries. Then there are the actual subjects of enemy nations who are living in Great Britain, most of them happily interned. There are also naturalized aliens from four countries (Germany, Austria, Turkey, and Bulgaria), and the laws of those four countries as to the status of citizenship are not alike. Again, there are naturalized aliens who were naturalized here before 1870, the year when the German Empire was constituted; and conceivably there may be some of our members, for example, who were citizens of Hanover, formerly practically a British possession, and some who before 1866 were citizens of Frankfurt, which was then a free and independent State. Then there are others who were naturalized after 1870 but before the 1st January, 1914; and there may be some persons—there cannot be many—who were naturalized after the 1st January, 1914,

and before the war broke out, and these are the only ones who are affected by the new German law that has been referred to. I do not believe we have one single member in that category. (MR. A. A. C. SWINTON: I know there are several, at any rate electrical engineers.) I doubt it. I made enquiries of the American Embassy, which represents the German Embassy, and I was referred to a man who was formerly and at that period Clerk to the German Consul-General in London, and he assured me that, so far as the German Consulate was aware, there were none of that class between the 1st January, 1914, and the 4th August, 1914. Then there are aliens who have naturalized as citizens of other countries, and who are our own members, so if we are going to turn them out because they have not become naturalized in England we shall lose at least two of the most distinguished American members we have, Mr. Nikola Tesla and Dr. C. P. Steinmetz. It seems to me we have a very great responsibility placed upon us to discover who are naturalized aliens and who are not. Someone must decide that question in each name that comes up. It cannot be decided *en bloc*. Some power of discrimination must therefore be given to the Council. Are members aware, as an example of the injustice that is done, that a member of this Institution, educated wholly in this country, as thoroughly British as anyone in this room, was just a year ago arrested by the police and, on mere suspicion, sent to be interned amongst alien enemies in the camp at Frimley, and spent there six miserable weeks, simply because he bore a German name? When at last Colonel Crompton, and I, and others procured an investigation into his case, it turned out that, so far from being a German, he was the son of an English clergyman, born in Jerusalem. It would be monstrous that we should expel any member without inquiring first whether he is really an alien or not. For my part I regret that this question has been raised, considering how few real aliens we have. I should not mind losing the few real enemy members; but it is a petty matter to be wasting the time of the Institution and going through all the formalities for the sake of a handful of objectionable people whom we know and whom we can deal with in our own way individually, under Article 41, whenever we please. Nevertheless I am prepared to waive my objections and to support the Council in the passing of the resolution proposed last week, provided the understanding is clearly preserved that there shall still rest with the Council the responsibility of determining who is and who is not an alien enemy; a thing which cannot be determined by the mere terms of a resolution.

MR. A. C. CRAMB: If Professor Thompson's remarks Mr. represent the views of the majority of the Council, I am not prepared to give the Council any power whatever.

MR. T. O. CALLENDER: I think the feeling of the members present at this meeting has shown that they do not wish it to be left to the Council to select members for expulsion because they are of German origin or for any other similar national reason. I believe it is the wish of the members that we should have a clearly defined rule barring certain nationalities from our membership, and I think that is right. With regard to naturalized alien members, each should be required to prove that he has completely and effectually cleared himself of his original nationality before he can remain a member of this Institution.

Pro  
Silv  
Tho

Mr.  
Calle

The PRESIDENT: With regard to Mr. Cramb's remark, no Member of the Council except the President can speak for the Council, and I can say fairly that neither Mr. Wordingham, on the one hand, nor Professor Thompson, on the other, is representative of the Council as a whole.

I should like to speak for a minute as a Corporate Member and not as President. We have made a bond, a contract, with a man who has come and settled in this country, and we have given him a scrap of paper. We have said to him: "You are a British subject." If that man is a British subject, and a British subject only, I will not, as a Corporate Member, vote in favour of expelling him from the Institution. These are my views as a Corporate Member, but the next time I speak I may as President have to put forward a different view.

I will now put the various points to the meeting:—

(1) "That the voting this evening be by ballot." (This was negatived almost unanimously.)

(2) "That members who are subjects of enemy countries be expelled." (This was declared by the President to be carried almost unanimously.)

(3) "That naturalized British subjects who have retained enemy nationality be expelled." (This was declared by the President to be carried almost unanimously.)

(4) "That naturalized British subjects who were formerly

subjects of a State now at war with Great Britain and Ireland, but who have definitely lost their alien nationality and are able to prove it to the complete satisfaction of the Council, be expelled." (This was declared by the President to be lost, a very large majority voting against.)

(5) "That no subject of Germany, Austria, or other countries with which we are or may be at war be elected after the war terminates." (This was declared by the President to be carried, about 40 voting for and 21 against.)

The President then suggested that a Committee should be nominated by the meeting to draw up one or more suitable forms of wording in regard to which the Corporate Members as a whole would be asked to express an opinion by post; and he added, in reply to a question asked by Mr. C. A. Baker, that if the Local Sections wished to communicate with the Council direct the Council would be very pleased to hear from them.

After further discussion it was then proposed by Mr. A. C. Cramb, seconded by Mr. A. Gay, and carried, that the Committee consist of the President as Chairman, the four Vice-Presidents—Mr. J. S. Highfield, Dr. A. Russell, Mr. Roger Smith, and Mr. C. H. Wordingham—together with Mr. L. B. Atkinson, Mr. F. Gill, Mr. J. H. Rider, and Mr. A. A. C. Swinton.

The meeting terminated at 7.20 p.m.

# 588TH ORDINARY MEETING, 9 MARCH, 1916.

Mr. C. P. SPARKS, President, took the chair at 8 p.m.

The minutes of the Ordinary Meeting held on 17 February, 1916, were taken as read, and were confirmed.

Messrs. H. M. Sayers and W. C. Clinton were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

## ELECTIONS.

### Member.

Du Pasquier, Arthur Edmund.

### Associate Members.

Carty, Samuel Wilfrid, 2nd      Ross, Tascarr Alan.  
Lieut., A.S.C.      Rowland, Thomas.  
Hewson, Francis Thomas,  
Lieut., R.N.

### Associates.

Ince, John Oscar.      Joyce, Dudley Vincent.

### Graduates.

Ansell, Arthur Molloy.      Khanna, Jagannath.  
Eckbo, Olaf Laache.      McDermott, James.  
Hastings, Albert Anthony.      Nagahama, Shigemaro.

### Students.

Barlow, Harold Everard M.      Edmondson, Richard.  
Butterworth, Hubert.      Eggins, Leonard George.  
Cass, Arthur Cyril.      Exley, Walter.  
Clayton, John Richard.      Fawcett, Herbert.  
De Murga, Henry.      Fleming, Robert Tyndall

## Students—continued.

Flint, Eustace William.	Payman, Saul.
Gadsden, James.	Platt, John Weld.
Garner, Richard Hough.	Reim, Ernest Philip.
Green, Laurence Everett.	Robinson, Henry.
Hartley, Robert Cliff.	Romeira, Manol Pinto.
Heaton, Reginald George.	Rose, Frederick Butter-
Jepson, Cecil.	worth.
Junqueira, Sebastião Maxi-	Rowles, Alec Henry, Ser-
miano.	geant, R.E.
Kennedy, Herbert Alex-	Sadleir, John Rothwell,
ander.	Sanderson, Douglas Eggle-
Khan, Abdul Ghefoor.	ston K.
Martins, Guilherme Bebi-	Taylor, Thomas Theodore.
anno.	Wai, On.
Noor-el-Deen, Youssif.	Wray, Thomas.

## TRANSFERS.

### Associate Member to Member.

Chapman, Walter Harvey.

### Associate to Associate Member.

Whitehouse, William Henry.

### Graduate to Associate Member.

Brazier, Clifford Claude H.	Honey, Harold.
Cater, Francis Leonard.	Reay, George Henry Noel,
Dods, Robert.	Capt., R.E.
Douglas, Arthur.	Wood, Donald Shipton,
Feloy, Joseph Pascall.	Quartermaster, R.A.M.C.
Grover, Charles.	(T.).

*Student to Associate Member.*

Brunning, Ernest John.	McMahon, Vincent Henry M.
Emtage, Edmund Lashley M.	Marston, Gordon Spencer.
Holbrook, Henry Stanley,	Meikle, James.
B.Sc.	Prince, George Reginald D.,
Keith, Claude Hilton, Lieut.,	Capt., R.F.
R.N.V.R.	Wallis, Leonard.
Low, Duncan Whyte.	Yeates, Arthur Cyril.

*Student to Graduate.*

Neale, Reginald Edgar, B.Sc.	Sloan, Thomas.
Smith, Leslie Victor.	

The following donations were announced as having been received, and the thanks of the meeting were accorded to the donors:—

*Benevolent Fund:* P. F. Allan, J. R. P. Lunn, F. W. Main, A. H. Morse, A. J. Newman, and A. J. Ramsey.

*Library:* A. H. Avery, Messrs. J. H. Bennett & Co., The Proprietors and Editor of "The Engineer's Year Book," Dr. A. Hay, H.M. Chief Inspector of Explosives, Dr. A. E. Kennelly, W. N. Y. King, D. Munro, The Royal Society of Edinburgh, Dr. C. P. Steinmetz, and The University of Missouri.

The President announced that the revised edition of the Working Rules had been completed and that copies would be available on and after the 13th March. He also mentioned that all the insurance companies had accepted these Rules as their standard.

A paper by Mr. E. V. Pannell, Associate Member, entitled "Continuous-current Railway Motors" (see page 449), was read in the absence of the author by Mr. Roger T. Smith, Vice-President, and discussed, and the meeting adjourned at 9.40 p.m.

## 589TH ORDINARY MEETING, 16 MARCH, 1916.

Mr. C. P. SPARKS, President, took the chair at 8 p.m.

The minutes of the Ordinary Meeting held on 9 March, 1916, were taken as read, and were confirmed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and it was ordered to be suspended in the Hall.

The President announced that in view of the Government restrictions in regard to the supply of paper, and

also owing to the great increase in its cost, the Council had decided to reduce the amount of matter published in the *Journal* and to publish it monthly, instead of fortnightly, until conditions were again normal.

A paper by Mr. N. W. Storer, entitled "The Use of Continuous Current for Terminal and Trunk-line Electrification," was read in the absence of the author by Mr. J. S. Peck, and discussed, and the meeting adjourned at 9.40 p.m.

## INSTITUTION NOTES.

## REWARDS FOR SERVICE IN THE FIELD.

## (SECOND LIST.)\*

**Military Cross.**

Sparks, Lieut. A. C.	Royal Engineers	Associate Member
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"For conspicuous gallantry and initiative when taking part with some infantry in a raid on the enemy's trenches. With a small R.E. party he made a very successful reconnaissance of the enemy's trenches and then exploded charges in two concrete structures."—*London Gazette*, 15 March, 1916.

**Mentioned in Dispatches.**

Angwin, Major	Lowland Signal Service R.E.	Associate Member
A. S.		
Carey-Thomas, Captain H.	London Army Troops, R.E.	Associate Member
Evans, Major L.	Royal Engineers	Associate Member
Morcom, Lieut. R. K.	Divisional Engineers, R.N.D.	Member

## MEMBERS ON MILITARY SERVICE.

## (SEVENTH LIST.)\*

## MEMBERS.

<i>Name.</i>	<i>Corps, etc.</i>	<i>Rank.</i>
Capper, D. S.	London University O.T.C.	Lieut.-Col.
Kensit, H. E. M.	Canadian Engineers	Sapper
Westwood, E. H. W.	Australian Imperial Force	Lieutenant

## ASSOCIATE MEMBERS.

Baumann, F. C.	London Electrical Engineers, R.E.	Sapper
Bedford, J. R.	Anti-Aircraft Corps, R.N.A.S.	Able Seaman
Birch, F.	Manchester University O.T.C.	Cadet
Bullock, J. B.	Royal Navy	Eng. Sub-Lieut.
Carty, S. W.	Army Service Corps	2nd Lieut.
Casper, C. C.	R.N.V.R.	Sub-Lieut.
Clark, E.	Australian Imperial Force	
Clayton, A. E.	London Electrical Engineers, R.E.	Sapper

\* See page 309.

\* See vol. 53, pp. 199, 320, 388 and 857, and vol. 54, pp. 121 and 403.

## ASSOCIATE MEMBERS—continued.

Name.	Corps, etc.	Rank.
Crowder, H. G. Y.	Canadian Field Artillery	Private
Date, W. H.	Royal Flying Corps	2nd Lieut.
Denison, N.	East Anglian R.E.	2nd Lieut.
Eadie, J. C.	British Red Cross	
Hamilton, W. G.	Royal Engineers	2nd Lieut.
Hewson, F. T.	Royal Navy	Lieutenant
Ingram, G.	London University O.T.C.	Cadet
Johnson, A. M.	Royal Flying Corps	2nd Class Air Mechanic
Lacy, T. S.	R.N.V.R.	Sub-Lieut.
Langford, T. H.	Artists' Rifles O.T.C.	Cadet
Matravers, F. G.	Royal Navy	Sub-Lieut.
Midgley, T. S.	Army Service Corps	Private
Partridge, T. G.	Punjab Light Horse	
Poulton, F. C.	Army Ordnance Dept.	Lieutenant
Redfern, W. D.	East Lancs Field Ambulance, R.A.M.C.	Private
Richardson, H. W.	—th Provisional Battalion	Private
Ross, T. A.	Royal Engineers	Lieutenant
Taberner, A. D.	Loyal North Lancashire Regt.	2nd Lieut.

## ASSOCIATE.

Ince, J. C.	Anti-Aircraft Corps, R.N.A.S.	Able Seaman
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## GRADUATES.

François, L. D.	Royal Engineers	Motor Cyclist
Smellie, A.	London Electrical Engineers, R.E.	Sapper
Walker, R. B.	Yorkshire Hussars Yeomanry	Captain

## STUDENTS.

Burton, R. G.	Artists' Rifles O.T.C.	Cadet
Cheel, E. S.	Artists' Rifles O.T.C.	Cadet
Coulthard, W. B.	London Electrical Engineers, R.E.	Sapper
DeLaney, M. L.	Royal Engineers	Lieutenant
Denton, P. H.	Royal Engineers	2nd Lieut.
Dixon, F.	Lancashire and Cheshire R.G.A.	Gunner
Driver, E. T.	Artists' Rifles O.T.C.	Cadet
Fisher, F. W.	R.N.V.R.	Sub-Lieut.
Jenkins, A. M.	London Electrical Engineers, R.E.	Sapper
Lawrence, F. H.	Officers' Cadet Unit, R.F.A.	Cadet
Lunnon, F. C.	R.N.V.R.	Sub-Lieut.
Mahon, A. T.	London Rifle Brigade	Private
Perrow, F. A. P.	South African Medical Corps	Lieutenant
Rowles, A. H.	Cornwall (Fortress) R.E.	Sergeant
Webster, L. H. V.	Royal Engineers	Sergeant

## DIVISIONAL ENGINEERS, ROYAL NAVAL DIVISION.

In December 1915 a fund was formed by past and present Members of Council for the purpose of sending extra supplies of food and tobacco to the men of the Signal Company of the Royal Naval Division.

The President has recently received the following letter from the Officer Commanding the Company in acknowledgment of a first consignment.

H.Q. SIGNAL COMPANY, R.N.D.,  
12 February, 1916.

SIR,

The Signal Company desire me to convey their thanks to the past and present Members of the Council, and their deep appreciation for the excellent gifts so kindly sent to them. The first consignment of 10 cases from Messrs. Fortnum and Mason arrived in good order last week, and the goods have to-day been distributed amongst the Signal Company men.

There seems to be great difficulty in obtaining a canteen. For months we had none at all, and now only a very inadequate one is available, open one day per week and with a very limited variety of goods. A supply of delicacies, such as you have sent, is therefore especially acceptable and greatly appreciated by all.

Knowing that the Institution takes a keen interest in the Company's doings, with the permission of the Censor I will add a few lines which may be of interest to you.

It is now just one year since the Company left England on active service, and our strength is 183 N.C.O.'s and men, and of these there are still serving here 102 who took part in the original landing at Cape Helles. I am proud to report that the Signal Company has constantly been congratulated on its good work in the field, and 30 per cent of the men who have served in Gallipoli have been awarded Certificates for Gallantry or Continuous Devotion to Duty.

Two officers and three men of the Company have been mentioned in General Sir Ian Hamilton's despatches.

No. 459, Corporal F. R. Smith (motor cyclist) and No. 200, Sapper J. H. Murray (lineman) have been awarded Distinguished Service Medals.

... ..

I am, etc.,

(Signed) G. W. HILDITCH,  
Captain R.M.

O.C. Signal Company, R.N.D.

## WIRING RULES.

The Seventh Edition (March 1916) of the Wiring Rules has now been completed. Among the changes in this edition are the extension of the Rules to include medium pressures, the provisions made for conductors with hard rubber-compound protection, the addition of a table showing the capacity of conduits, and of a rule recommending colours for the conductors.

Copies may be obtained, at the price of sixpence per copy (or sevenpence, post free), from the Secretary of the Institution, or from Messrs. E. & F. N. Spon, Ltd., 57 Haymarket, London, S.W.

## PUBLICATION OF THE JOURNAL.

In view of the Government restrictions in regard to the supply of paper, and also owing to the great increase in its cost, the Council have decided to reduce the amount of matter in the *Journal* and to publish it monthly, instead of fortnightly, until conditions are again normal. The last fortnightly Part (No. 257) was dated 1 March, 1916.

## AN APPEAL TO EMPLOYERS.

The Home Secretary and the President of the Board of Trade have asked that the following appeal be brought to the notice of employers :

"We desire to call the attention of employers in the manufacturing industries to the urgent necessity of concerted action for the purpose of making good the loss of labour caused by withdrawal of men for the Forces.

"The maintenance in the fullest vigour of the manufacturing industries which are necessary to the provision of Government supplies, the support of the population and our export trade, is of vital importance to the country at the present time. On it hang very largely the successful conclusion of the war and the continued prosperity of the nation in the years which will follow the war.

"The manufacturing industries are face to face with a situation which demands prompt and vigorous action. Men are rapidly being withdrawn—the Board of Trade returns show that a large amount of plant is already standing idle—and many complaints are being received from manufacturers that the necessary labour cannot be got.

"There is one source, and one only, from which the shortage can be made good—that is, the great body of women who are at present unoccupied or engaged only in work not of an essential character. Many of these women have worked in factories and have already had an industrial training—they form an asset of immense importance to the country at the present time and every effort must be made to induce those who are able to come to the assistance of the country in this crisis. Previous training, however, is not essential—since the outbreak of war women have given ample proof of their ability to fill up the gaps in the ranks of industry and to undertake work hitherto regarded as men's.

"We appeal, therefore, on behalf of the Government, to every employer who is finding his business threatened with diminished productivity through the loss of men, not to accept such diminution as an inevitable consequence of the war, but to make every possible effort to maintain his production by using women, whether in direct substitution for the men who have been withdrawn or by some division or re-arrangement of his work.

"The Home Office and the Board of Trade are prepared to give employers all the help in their power in taking this course.

"The task of bringing into industry the reserves of women's labour to fill temporarily the places left vacant by the withdrawal of the men, is one that can only be rapidly and successfully accomplished by concerted action. Individual effort on the part of employers has only been partially successful, in some cases it has failed entirely, in obtaining women substitutes.

"If overlapping, competition, and waste of effort are to

be avoided, recourse must be had to central machinery in each industrial area to organize the supply of women's labour. The needs of the industries must be ascertained and steps taken to attract the number of women required. The Labour Exchanges with their organization and staff are ready to hand and special arrangements are being made to utilize them to the fullest extent for this purpose. But the full co-operation of employers is equally necessary ; they alone can determine how their businesses can be re-organized on a basis of women's labour and the number of women they will require. It is only if the Government are placed in possession of the needs of employers that they can form an accurate judgment of the situation and take useful action.

"We urge every employer, therefore, who has not already done so to do two things :—

- "(1) To review the organization of his works in order to ascertain how it is possible by re-arrangement of work and other measures profitably to employ, as temporary substitutes, as large a number of women workers as possible.
- "(2) To send to the local Labour Exchange at once—and from time to time as the situation develops—particulars of his requirements for women labour, with the fullest possible details as to the classes of work, and the qualifications required.

"It is necessary to know what the demands of employers in an industry are likely to be before women can be invited to offer themselves for work in the industry.

"For the work of canvassing and drawing in the reserves of women, it is proposed to invite local assistance of persons qualified by their experience of industry and social work, and steps are already being taken to make arrangements for this.

"The introduction of women into a factory or a department where previously men have been employed may cause the employer some difficulties in the matter of arranging for conditions of work suitable to women, or complying with the requirements of the Factory Acts—but in many industries these have already been overcome as a result of discussion between the employers or their associations and the officials of the Home Office, and every effort will be made by the Home Office and the Factory Inspectors to advise and assist employers in meeting such difficulties.

"We are confident that the women of the country will respond to any call that may be made, but the first step rests with the employers—to re-organize their work and to give the call.

"(Signed) HERBERT SAMUEL.

"(Signed) WALTER RUNCIMAN.

"6 March, 1916."

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## THE USE OF CONTINUOUS CURRENT FOR TERMINAL AND TRUNK-LINE ELECTRIFICATION.

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In the excellent papers dealing with the electrification of railways that have been recently presented before the Institution, notably those by Messrs. Roger T. Smith\* and H. W. Firth,† the subject is dealt with largely from the standpoint of the railway man, and much food for thought is presented for the manufacturers and designers of electric railway equipment. The problem is stated in no uncertain terms, and it is made perfectly clear that the electrical engineer must present a satisfactory solution of the problem before electrification can extend far beyond the suburbs of the large cities. The difficulties involved in handling the peak loads during the rush hours are carefully dealt with and the desirable characteristics of motive power are discussed. It would be presumption on the part of the present author to discuss what is purely a transportation matter, the question of handling trains in Great Britain where the conditions are so different from those in America, so that this paper will deal chiefly with the characteristics and possibilities of the continuous-current motor for handling trains in the most economical and satisfactory manner, not only on one line but for interchanging equipments on lines where different conditions prevail.

### THE SERIES MOTOR.

It is only about 30 years since the electric motor was first used in real commercial railway service. Many experiments were made prior to that time, but it is a noteworthy fact that the electric railway motor did not become commercial until the first continuous-current series-wound motor was built and geared directly to the car axle. After that event the progress of electric railways was by leaps and bounds. Electrification was of course confined for some years to tramways, or street railways as they are usually termed in America, but gradually it extended into fields of heavier duty such as elevated and underground railways, and in a few cases to locomotives.

The invention of the multiple-unit control system gave a great impetus to its growth, especially in heavy city and suburban train service, and now electric motors have been applied to a greater or less extent to practically all classes of railway service.

A great many changes have been made in the continuous-current motor in the last 25 years. As might have been expected, the requirements of a motor for railway service were at first but little understood; in fact, few electric motors were used for any purpose and they were a mystery to most engineers. In the first motors the insulation was poor, the mechanical design was worse, and the commutation so bad that the copper in the commutators was gradually transferred to the pavement beneath the cars. Of course, such a condition did not long obtain, and the improvement has been both rapid and continuous from that day to this, when the up-to-date, continuous-current, commutating-pole, self-ventilated, and oil-lubricated railway motor leaves little to be desired, either electrically or mechanically.

Motors have been designed and built in all sizes and shapes, and the design is now so thoroughly understood that the performance under any operating conditions can be very accurately predetermined; but while the design of the motor has been revolutionized and perfected, the principles involved that led to the selection of the series motor are the same as they were 25 years ago when the advantages of the steep speed and torque curves were first seen by some of the designers. These characteristics have proved to be admirably adapted not only to tramways and heavy multiple-unit trains in frequent stopping service, but to the requirements of locomotives for long-haul, passenger and freight service.

The series motor has been so successful and has shown itself to be so superior to all other types of railway motors, that it is now used almost universally for tramways, street and interurban or radial railways, underground and elevated lines, and for the electrification of the terminal and suburban lines of steam railways. The motor is deservedly

\* *Journal I.E.E.*, vol. 52, p. 293, 1914.

† *Ibid.*, vol. 52, p. 1886, 1914.

popular, and is so firmly established that it will be difficult ever to displace it as long as electricity continues to be the motive power, even though it were possible to bring forward a type of motor with some superior features. In addition to giving the most efficient performance, it is well known that the steep speed curve makes the series motor more nearly "fool proof," and therefore more reliable and cheaper to maintain than any other continuous-current type, whether it be shunt, compound wound, or separately excited. It introduces a degree of elasticity in the motor that enables it to withstand the severe service of rapidly accelerating heavy trains and developing overload torques that would be impossible in any other type of motor. It also gives the best commutation and is least subject to injury resulting from the fluctuating line voltages that are common to all electric railways. It is well known that a shunt or compound motor is very sensitive in commutation to sudden changes in voltage, and that practically every attempt to use such motors in railway service has come to grief. The field of such a motor is so much more sluggish than that of the series motor that flashing is almost inevitable where sudden changes of voltage take place on lines of heavy capacity. It is a matter of record that voltages of more than three times the normal have been reached on heavy-capacity third-rail lines due to surges following the opening of heavy loads or short-circuits, and that even series motors must be well designed to escape flashing in such cases.

While a variable-speed shunt motor possesses certain theoretical advantages in improving the efficiency of operation if it could be made as reliable, practically the motor is heavier and more expensive, due to the heavy fine-wire shunt coils which would also be liable to be a continual source of trouble. Moreover, no greater speed variation is possible with it than with the series motor, because this depends on the armature and the allowable ratio between the field and armature ampere-turns necessary to secure stability.

#### SERIES-MOTOR CHARACTERISTICS.

To begin with, it may be as well to explain that the series motor as generally used has not the most efficient characteristics. It is the series motor in its simplest form that is now used most extensively. As a rule the field becomes saturated at a current corresponding to about the 1-hour rating. This is the result of the effort on the part of the designers to secure the maximum output for 1-hour rating with the minimum weight of material. Most of the early designers of railway motors secured a certain amount of speed control by varying the effective turns on the field. This was the only way they had to obtain a variation in speed, as the series-parallel control did not appear until the early nineties; but after that was introduced, the control of the field was abandoned, partly to simplify the equipment and partly because of the grave troubles from commutation and overload which were introduced by running on the weak field. Thanks to the great progress that has been made in motor design, notably in the development of the commutating pole and in the ability to predetermine the work demanded of the motor for any class of service, these objections no longer obtain and field control is once more being employed where the

service conditions justify its use. While field control will give the greatest economy in accelerating, its introduction has again called attention to the advantages of the motor with the steep speed curve and the unsaturated field.

Fig. 1 shows corresponding speed and torque curves for two motors—one with saturated and the other with unsaturated magnetic circuits. It will be seen that the speed curves cross at approximately 42 miles per hour (m.p.h.), but at the 1-hour rating of the motor, which is practically 350 amperes, the speed of the saturated motor is 37 m.p.h., while the other runs at 33 m.p.h. Stating it in another way, the tractive effort of 2,500 lb. which is developed by the saturated motor at its full load of 350 amperes, would be developed by the unsaturated motor with a current of about 320 amperes. For frequent stopping service it will be seen at once that the unsaturated motor will operate more efficiently since it accelerates with so much less current. The difference is still more pronounced on overloads. This also brings out the fact that the heating current, or the root-mean-square current as it is commonly known, will be very materially decreased in the unsaturated motor for a given service and, consequently, an unsaturated motor of a given rating will have a greater service capacity; or, with equal margin for a given service, an unsaturated motor will require a smaller rating than a saturated motor compared on either the 1-hour or continuous basis. If this point were thoroughly borne in mind, the manufacturer of the unsaturated motor would not be penalized on account of small rating, or on account of greater weight with equal ratings, and the railway company would operate with greater efficiency.

Fig. 2 brings this out very clearly in terms which cannot be misunderstood. It shows in one curve the rheostatic losses in accelerating one ton at a specified rate by means of series-parallel control, and certain motor efficiencies. This curve shows that the rheostatic losses vary directly as the square of the speed at which the last resistance is cut out of the motor circuit, or at which the motor curve at full voltage is reached. Referring to Fig. 1, if the load were accelerated at a tractive effort of 3,300 lb., the motor curve on the saturated motor would be reached at a speed of 35 m.p.h., while the unsaturated motor would reach the motor curve with the same tractive effort with about 10 per cent less current and at a speed of 31½ m.p.h. Referring to Fig. 2, it will be seen that the rheostatic losses in the one case would be 22½ watt-hours per ton, and in the other 18 watt-hours per ton, i.e. a saving of 4½ watt-hours per ton for each acceleration. Of course a motor geared for such a high speed as this would not make more than 1 or 1½ stops per mile, but in any case there would be a certain definite saving for every acceleration that the motors are required to make.

#### FIELD CONTROL.

The use of field control still further improves the efficiency of acceleration, and offers, where desirable, additional operating speeds. This was first applied in recent years to the alternating-current-continuous-current locomotives installed on the New York, New Haven, and Hartford Railroad to provide some speed control on the continuous-current zone of operation. The motors were operated on the single-phase lines with two halves of the

field in parallel; on the continuous-current lines the coils were all in series and the field was shunted in order to obtain higher speeds. The first large installation with purely continuous-current locomotives was on the Pennsylvania, New York, and Long Island Railroad, for the New York terminal of the Pennsylvania Railroad. These locomotives have been described on numerous occasions, but they are mentioned again simply to show the extent to which field control can be safely carried to secure efficient operation and wide range of speed under favourable conditions.

Fig. 3 shows the curve of the motor for this locomotive, which it will be remembered has only two motors. The usual series-parallel connections combined with field

in those comparisons, owing to insufficient information on the subject, and he believes that if a continuous-current locomotive with the range of speed at constant output which is given by the Pennsylvania locomotive were applied to a given load condition, it would prove to be better adapted to the service than any steam locomotive, notwithstanding the very great improvements that have been made in steam locomotives in recent years. The Pennsylvania locomotive curves, for instance, show that it will develop an output of 1,200 h.p. at any speed between 42 and 76 m.p.h. It will develop 1,600 h.p. over a range of speed from 36 to 60 m.p.h., or 2,000 h.p. between 32 and 52 m.p.h.; it will develop 3,000 h.p. over a range from 27 to 41 m.p.h., or 4,000 h.p. from 25 to 35 m.p.h.

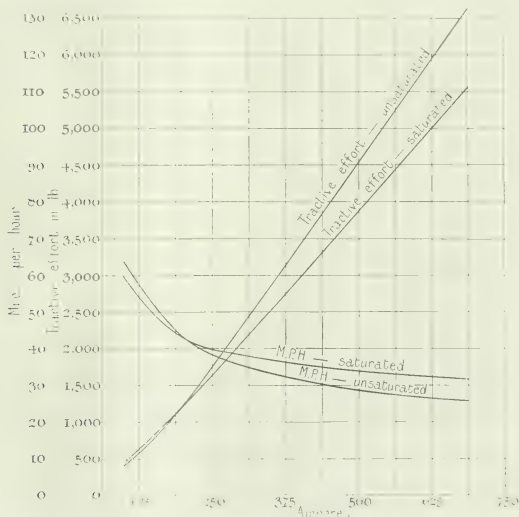


FIG. 1.—Comparison of characteristic curves of saturated and unsaturated field motors, 200 h.p., 600 volts.

control give four speed curves. These curves simply show the maximum range of speed at which the motor is designed to operate at normal and half voltages, but there are two intermediate speed curves on each voltage which may be used if desired between the full field and the normal field position.

There have been criticisms of electric locomotives in comparison with steam in several papers, notably that by Mr. Roger T. Smith mentioned above, and one by Mr. E. H. McHenry before the International Engineering Congress in San Francisco, September 1915. The author feels that the electric locomotive scarcely received justice

If locomotives are to be compared simply on the basis of the continuous or the 1-hour rating, comparisons are likely to be misleading. The speed control shown on the curves for the Pennsylvania locomotives is quite within the range of possibility for well-designed continuous-current locomotives, and while it is admitted that the electric locomotive does not entirely meet the speed-torque characteristic of the steam locomotive which seems to be so desirable for express service, the author believes there are few cases where this is necessary over the wide range of speed for any considerable length of time. In cases where a heavy tractive effort is required for short periods of time, the

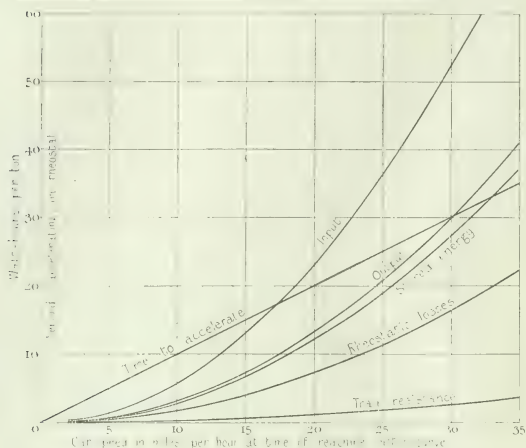


FIG. 2.—Analysis of power consumption in straight-line acceleration.

Data—Weight	1 ton (2,240 lb.)
Acceleration	1 m.p.h. per sec.
Total Tractive Effort	121 lb.
Train Resistance	11 lb.
Allowance for Rotating Inertia	75 per cent
Control	Series-parallel
Motor Efficiency at Normal Voltage	88 per cent
Voltage-drop in Motor	5 per cent

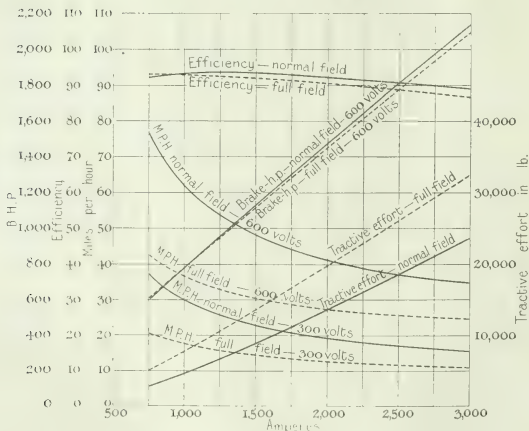


FIG. 3.—Westinghouse No. 315A railway motor, 600 volts, 72-in. wheels, 9/16 in. air-gap.

electric locomotive has the enormous superiority of being able to handle the load at a higher speed.

As touching on the economy secured by field control with a locomotive such as the Pennsylvania, it is obvious that the rheostatic losses will be so small as to be of very little importance, as combinations of control giving series, series-parallel, and parallel control with variations in field strength are adopted. One example from the Pennsylvania locomotive curve will show the reduction in rheostatic losses that is made by the use of field control in parallel only. Assuming that the locomotive for normal operation must have the speed curve as shown by the normal field, that it is accelerated at the tractive effort of 40,000 lb., the motor curve would be reached at a speed of 36 m.p.h. without field control, or a speed of 27½ m.p.h. with the same tractive effort and field control. According to Fig. 2 the rheostatic loss would be 24 watt-hours per ton in the one case and 13.8 in the other. If the field control were also utilized in series the locomotive would be accelerated from a speed of 13.5 to 18 m.p.h. without resistance in the circuit, and a further reduction of nearly 3.5 watt-hours per ton-mile would be made.

Ordinarily it may be assumed as certain that when maximum use is made of a field-control equipment it will reduce the rheostatic losses to not more than one-half of what they would be with the usual series-parallel arrangement. The total saving per ton-mile will of course depend on the number of accelerations made.

In general, if it is desired to reduce the power consumption to a minimum, the unsaturated motor having a steep speed curve is to be recommended either with or without field control wherever the service requires frequent acceleration or very heavy grades are encountered. The saturated-field motor or the one having the flat speed curve is to be recommended for use only where it is desirable to obtain a more nearly constant speed over long runs, regardless of variations in grades and trailing loads, and reduces the chances of mechanical damage by limiting the speed. Such a curve entails much greater fluctuations in load on the motors, reduces their overload capacity, and also increases the fluctuations on the line and sub-stations. It is a mistake to think that the field-control motor is going to be materially heavier for a given service than the simpler form of series motor. It may have a lower rating for a given weight of motor, but in a class of service where the duty is confined to accelerating work, as is commonly the case in city and suburban lines, the R.M.S. current demanded of the motor with field control will be less and therefore the motor will be very little heavier than a plain series motor.

#### REGENERATIVE CONTROL.

A great deal has been written and spoken in regard to the possible savings that can be effected by regenerating the power that is stored in a moving train during the stopping period, and also of saving the energy developed by the train in descending grades. Many attempts to regenerate have been made by utilizing shunt motors, but as a matter of fact such systems have thus far, for one reason or another, proved to be unsatisfactory. The problem will never be given up as long as there is a possibility of saving any considerable portion of the power which is now expended in wearing out brake-shoes and wheel

tyres. It is well known that 50 per cent of the total power taken from the line is expended in this way on a great many lines, so that it is a matter of great importance.

The scheme adopted long ago on the Central London Railway, of saving this energy by elevating the station tracks, is one that can be tried in special cases with excellent results. It has one great advantage over any scheme of electrical regeneration in that it adds nothing to the equipment and makes the work easier, so that smaller motors may be used. However, it has its limitations as shown on the curve in Fig. 4, which gives the height to which a train must be raised in order to save all of the stored energy. (This curve and Fig. 5 which follows have been given before by the author, but are particularly pertinent to this paper.) It will be seen from Fig. 4 that a train operating at 30 m.p.h. would stop without brakes if allowed to climb to a height of 30 ft. A 14-ft. elevation would be required to absorb all of the energy in a train moving at 20 m.p.h. Of course it would not be feasible to save all of

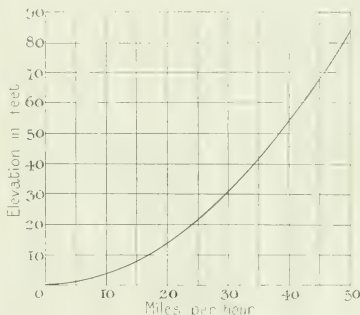


FIG. 4. —Track elevation required to bring a train to rest.

the stored energy, nor in fact would it be feasible to save any large part of it on a line having long trains and a high schedule speed. That it is possible to make very considerable savings, however, is shown not only on the Central London Railway but on the South Side Line of the Chicago Elevated Railway. Such a plan as this for saving power is not practical for the large majority of railways, so that some other scheme must be adopted, but it may be noted that any scheme of electrical regeneration may be supplemented by the elevated station tracks.

As a matter of fact such a scheme is already pretty well developed and it is hoped that it will soon be in commercial operation. It involves the use of the standard series motor, with separate excitation during regenerative periods. The control may be entirely automatic from the time it is applied until the lowest speed is reached at which the motors when connected in series can develop the line voltage. At the same time it can be stopped at any desired speed. The regeneration at high speed is with the motors connected in parallel, and the change

from parallel to series is effected by a bridging method especially adapted to this purpose. There is no break in the retardation of the train from the maximum speed until it comes to a standstill; for the control is so arranged that the air brakes may be applied as soon as the minimum regenerating speed is reached. The use of the standard series motor in this connection is of the greatest importance, and it is also noteworthy that the motor designed for field control also assists in securing the maximum saving of energy owing to the fact that the regeneration can be carried to a lower speed.

It is usual practice in equipments for heavy multiple-unit service for city and suburban traffic to have the motors geared for a speed of about 15 to 18 m.p.h. at the 1-hour rating of the motors. Such an equipment will retard the train by regeneration down to a speed of 8 to 10 m.p.h. Fig. 5 is plotted so as to show the possible saving that can be effected by regenerating down to a speed of 10 m.p.h. The top curve shows the amount of energy that is stored in the car. From that is deducted the amount left in the

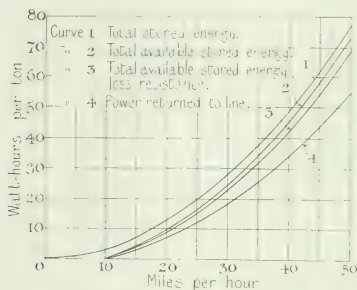


Fig. 5.—Analysis of power regeneration, regenerating to 10 miles per hour.

car at a speed of 10 m.p.h. The next curve deducts the amount that is required to overcome train resistance at a specified rate of braking down to 10 m.p.h. From this curve is deducted the amount of power that is lost in the equipment during regeneration. In this case the efficiency of regeneration is assumed to be 80 per cent, which allows for a considerable loss in the auxiliaries. The lowest curve shows the energy in watt-hours per ton that should be restored to the line under the specified conditions from any speed under 50 m.p.h. down to 10 m.p.h. Owing to the fact that the equipment required to permit regeneration adds somewhat to the weight of the car, the net saving in power will be somewhat less than that shown. A single example will suffice to show what may be expected from this system. At a speed of 25 m.p.h. the amount of stored energy is 19 watt-hours per ton. The curve indicates that not less than 12 watt-hours per ton will be restored to the line. The additional weight of the equipment may bring the net saving down to 10 watt-hours per ton with the size of equipments on which these

curves are based. Smaller and less efficient equipments might reduce the saving to a still lower value, but it is probable that in any case at least 45 per cent of the stored energy can be returned to the line. If this stored energy amounts to 50 per cent of the power taken from the line, the net reduction in power consumption should be more than 20 per cent.

Owing to the fact that none of these equipments is yet in commercial service, it is impossible for a further description of the method adopted to be given at this time. It can be stated, however, that it is quite practicable to apply it not only for the automatic retardation, as described above, but for use in controlling locomotives in descending grades. Perfect hand control can be obtained, together with a variation in speed which makes the equipment even more desirable than the automatic regeneration of the 3-phase induction motor.

From the foregoing it will be seen that the desirable economies in the use of electric power in operating railways, which were mentioned in Mr. Mordey's remarks on Mr. Roger T. Smith's paper,<sup>2</sup> are possibly nearer to a realization than he anticipated at the time he spoke. It has already been explained that it is possible to secure with continuous-current motors a very flexible system of speed control which will fit an equipment to perform satisfactorily in several different classes of service.

#### LINE VOLTAGE.

During the 30 years covering the development of electric railways, the question of line voltage has always been uppermost. The voltage adopted for the first successful line was approximately 450. This was higher than the insulation of the motors could stand without very frequent breakdowns. So desirable was it, however, to have a higher voltage on the line, that it has been continually pushed higher and higher, and always, until the last few years, being about as high as the motors could stand. By successive steps the line voltage has been raised until the standard for most tramways and suburban lines is now 600 volts. This seems to be the economical limit for small equipments such as tramway motors, and to have many advantages for heavy suburban work. If only the motor and control equipments were to be considered, 600 volts would probably continue to be the standard, not only for suburban and terminal electrifications, but for all classes of service. It is well known, however, that the tendency to adopt higher voltages on account of the economy of transmission and the necessity in some cases for using the overhead contact wire for heavy service, has been increasing at a very rapid rate, and in the United States a voltage of 1,200 to 1,500 has become the standard for interurban railways, whilst pressures of 2,400 and 3,000 volts are also being used in one or two instances. A continuous-current voltage of 5,000 has also been in use on an experimental equipment of the Michigan United Traction Company for the past seven or eight months. In England 1,200 and 1,500-volt lines are now in operation, and a 3,500-volt experimental equipment has been in use for several years on the Lancashire and Yorkshire Railway. In other parts of the world, voltages of 750, 800, and 1,000 are also in use. The tendency among

<sup>2</sup> *Journal I.E.E.*, vol. 52, p. 371, 1914

the railways centering in London seems to be to adopt the 600-volt third-rail system. This is used interchangeably on the Metropolitan District, the London and North-Western, and the London and South-Western Railways. The 1,500-volt line is on the North-Eastern Railway, where it is used for the haulage of mineral trains, the locomotives taking current from two overhead wires in parallel. The 1,200-volt line which is about to begin operation on the Manchester end of the Lancashire and Yorkshire Railway is used in connection with a new type of third rail, the contact surface of which is located on the side of the rail farthest from the running rail.

In view of the possibility of still higher voltages and other contact systems being introduced in Great Britain, the question of interchangeability of equipments has become very prominent. The present great war has shown the necessity for this more powerfully than any argument in mere words could possibly do. It is certain that to secure a maximum efficiency out of the transportation systems of the country in time of war, any equipment should be able to operate satisfactorily on any line. On the other hand, if each railway were to stand by itself there would probably be within a few years railways operating with practically all the voltages from 600 to the maximum. This would be due in part to local conditions and partly to the variations in the opinions of the engineers in charge. There would also be a great number of contact devices and of conductors located at various distances from the running rail.

Two conditions of prime importance are necessary to enable equipments to operate interchangeably over different lines, namely:

- (1) The contact conductors must be so arranged that any equipment can take power from any line without change.
- (2) Every equipment must be so designed as to operate at required speeds over the various voltages of the different lines.

It seems especially pertinent to the occasion that everyone should have a full knowledge of the possibilities and the difficulties of interchanging continuous-current equipments over lines having several different voltages. It is the purpose of the author to discuss briefly the possibilities and to show the complications that are introduced. The subject may be divided into four topics:

- (1) The contact and collector system.
- (2) The motor.
- (3) The control.
- (4) The auxiliary power equipment.

#### (1) CONTACT AND COLLECTOR SYSTEM.

This subject will be considered first because before any interchange of equipments is possible it is necessary to standardize the contact system so that, as stated above, a car or locomotive from one line can collect current from a contact rail or trolley on any other line.

The usual contact system for all lines in Great Britain using a pressure of 800 volts or less, except tramways, consists of some form of contact rail or rails mounted either outside of the running rails or between them. The oldest and most frequently seen is a top contact or over-running type of rail. A new form of rail having the side

contact has been introduced on the Lancashire and Yorkshire Railway, the latter for use on 1,200 volts. In some cases, as in the London Underground Railways, a return conductor is also used. There will probably be no difficulty in locating the return rail so that the same collector can operate on any of them. It is also possible where the contact surfaces are properly located to have a single contact-shoe satisfactory for collecting current from either the under-running or the over-running type of rail. Such interchangeability is possible between the Pennsylvania over-running rail and the New York Central under-running rail at New York.

Where it is necessary to have the rails located at different distances outside of the running rail or at different heights, it becomes necessary to adopt a collector shoe which can be shifted easily and quickly so as to accommodate it to different conditions. For multiple-unit service this would have to be done from the motorman's compartment, preferably by the use of compressed air electromagnetically controlled. There are several instances where equipments operate interchangeably on the third rail and the overhead trolley system, and where the contact shoes are under such control that when the car leaves the third-rail zone the shoes are lifted out of the way and disconnected from the live conductors. There is no reason to suppose that it would be impossible to shift the shoes in other directions in order to make contact with rails located at different places, provided that the distance were not too great to be covered. However, such things should be avoided if in any way possible. The author can see no possibility for interchanging equipments between the top and bottom contact rails and the side contact such as used on the Lancashire and Yorkshire Railway.

The same statements hold true in regard to overhead conductors. The problem there is much simpler, because it seems to be the universal practice to locate the overhead conductor above the centre line of the track and to keep its height between certain definite limits which must in all cases clear the rolling-stock. In this case it is more a question of adopting the proper kind of contact shoe which, while being subject to many variations, is also subject to many solutions. It should be possible to adopt a collector which will operate satisfactorily on any overhead line. It is sometimes necessary to have both a pantograph and a wheel trolley on interurban cars in the United States where the cars operate over high-voltage lines between cities and over the standard 600-volt lines in towns, but such complications are undesirable and should be avoided.

#### (2) MOTORS.

It is generally well understood by all who are acquainted with electrical apparatus that a continuous-current armature has practically the same current capacity regardless of the voltage applied to its terminals, the latter being limited to a certain maximum as determined by commutation characteristics and speed. It is understood that increasing the voltage for a given current also increases the core loss, but this is largely compensated for by an increased speed which gives greater ventilation. This is especially true with the late types of self-ventilating motors. It may therefore be assumed as correct within a very few per cent

that the horse-power or kilowatt rating of a motor is proportional to the voltage applied to its armature terminals. It follows, therefore, that the normal capacity can be secured only by maintaining the normal rated voltage on the armature terminals. This, then, is the basis on which any proposition that involves interchanging equipments on different voltages must stand. It will be seen at once that the most advantageous results may be secured if the various line voltages are multiples of the rated voltage of the individual armatures, so that they may be connected in various combinations depending on the line voltage. To obtain the rated output from an equipment of motors operating on multiple voltages, it is necessary to manipulate the control circuits so that each armature will always receive the same running voltage regardless of the line voltage.

As 600 volts is recognized as the standard voltage for most city and suburban railways, the natural or desirable higher voltages adopted or proposed are usually 1,200, 2,400, 3,600, and 4,800. As most of the so-called 1,200-volt lines operate with a sub-station voltage of 1,300 to 1,350 volts, practically the same equipments can be used on the 1,500-volt lines, which offers from the sub-station and line-loss standpoint a considerable advantage over the nominal 1,200 volts. A voltage of 1,500 has been adopted in several notable instances and bids fair to have a considerably wider field of usefulness for interurban and light-railway service. Taken by itself it is a very desirable voltage, as it is about the maximum on which the motors and control equipment of the form usually adopted on the 600-volt line can be used without considerable increase in the cost. A voltage of 1,500 is therefore very satisfactory from the equipment standpoint. It is not, however, usually considered to be high enough for trunk-line service, as it entails very heavy expenditures for line copper and for sub-stations, and makes the collection of heavy powers difficult. It is also at a disadvantage when it becomes necessary to interchange 1,500-volt equipments over 1,200- and 600-volt lines.

Fig. 6 shows the speed curves that will be secured on a motor designed for a normal voltage of 1,500 when operated at lower voltages. With a current of 150 amperes, giving a tractive effort of 4,500 lb., the speeds are 22½, 17½, 10½, and 8¼ m.p.h. respectively at 1,500, 1,200, 750, and 600 volts.

To consider the matter of interchangeability in specific instances the following examples are cited:

(a) Assume that the equipment is required to operate over a 600-volt line at full speed. The armatures must then be wound for 600 volts. It is also required to operate over 1,200-, 1,500-, and 2,400-volt circuits. It will be seen at once that if series-parallel control is to be obtained at the high voltage, there must be two sets of motors, each set having four armatures connected in series, or a total of eight armatures. If these armatures are connected two in series on 1,200 volts, full speed may be secured. On 1,500 volts, however, it would be necessary to have the motors connected four in series, or to take a chance on raising the normal voltage on each armature to 750 volts. This would in some instances be possible as regards commutation, but would give 25 per cent higher speed.

Operating on 1,500 volts with four armatures in series, as with 2,400 volts, the speed and kilowatt capacity would

only be 62½ per cent of the normal, while on the other three voltages of 600, 1,200, and 2,400 it would be normal.

(b) If equipments are required to operate over these same voltages, but it is found that half speed on 600 volts is sufficient, as would be frequently the case, the armatures would be wound for 1,200 volts and full speed would be secured with series-parallel control on 2,400 and 1,200 volts, and 62½ per cent of normal speed on 1,500 volts, or the risk might be taken of running the 1,200-volt motor on 1,500 volts. In this case only four armatures are needed for the equipment.

(c) If it is required to operate at a maximum voltage of 3,000 and also at 2,400, 1,500, 1,200, and 600, it would be desirable to have at least four armatures in series on the higher voltage. These would be wound for 750 volts.

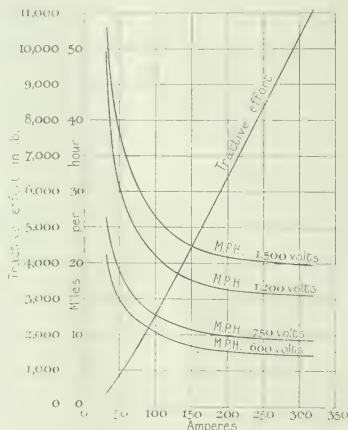


FIG. 6.—250-h.p. 1187.5-kw. railway motor, normal voltage 1,500.

The speeds for the different line voltages, then, with combinations of four in series, two in series, and all in parallel, with armatures wound for 750 volts, would give full output at 3,000 and 1,500 volts, and 80 per cent of the normal speed and output at 2,400, 1,200, and 600 volts. If only four armatures were used it would be desirable to connect them permanently in series on the 3,000-volt system. This would probably be the case where equipments were designed primarily for operation on the lower voltages.

(d) If 3,600 volts is the maximum with eight armatures on the locomotive, all of the above-named lower voltages may be covered and full speed and output will be obtained only on 3,600 volts; 83⅓ per cent of the normal rating and speed would be secured at 3,000 and 1,500 volts, and 66⅔ per cent at 2,400, 1,200, and 600 volts.

(c) With 4,800 volts on the line and four motors connected permanently in series at this voltage, full speed and output can be obtained with 2,400 and 1,200 volts, and half speed at 600 volts; the output and speed at 3,000 and 1,500 volts will be 62½ per cent of normal.

The combinations which can be effected in this way are endless, but the above will suffice to illustrate what may be expected in bad cases. In this connection, as illustrating what may be done to meet extraordinary conditions, may be mentioned the 5,000-volt car equipment which is in operation on the Grass Lake Line of the Michigan United Traction Company at Jackson, Michigan, U.S.A. This car is required to operate over about 10 miles of suburban line with 5,000 volts on the trolley and also over two miles of 600-volt line in the City of Jackson. Series-parallel control is used on the 5,000-volt line, and a balancing speed of 50 m.p.h. is normally reached. On 600 volts the four sets of armatures are connected in parallel and a speed of 18 to 20 m.p.h. is reached by shunting the fields of the motors. This speed is ample to make the schedule required in the city limits; and while the armatures are worked somewhat harder than usual, on account of the low voltage at which they have to develop their power, the equipment is operating on this portion of the line so small a proportion of the time that the motors can easily stand the service.

The author believes that this method of operation can be followed successfully in a great many instances where equipments designed for high-voltage service are required to operate for short distances over low-voltage lines. It is quite practicable to shunt the motor fields down to a very low value in such cases, as there will be no danger of flashing at the low voltages.

Another possibility of adapting 600-volt equipments for temporary operation over 1,200-volt lines is to install sufficient resistance in the equipments to operate the motors connected permanently two in series with rheostatic control. This would apply particularly to 2-motor equipments. In such a case the motors would have to be insulated for the higher voltage.

It is undesirable to equip cars with more than four motors each, as the complication and cost would become too great. With the locomotive, however, it is quite practicable to operate with eight motors, as is shown by the New York, New Haven, and Hartford geared locomotive which has eight motors connected in pairs to four driving axles, and the New York Central locomotives of the latest type which have eight motors each mounted on a separate driving axle. It is possible, also, that the twin-armature type of motor used on the 5,000-volt equipment just mentioned may be made satisfactory for operating all eight armatures in parallel on the lower voltages. Owing to the peculiar conditions involved in the magnetic circuit, however, it is not at all certain that they can be operated satisfactorily in this manner. It could probably be done, but it might be necessary to adjust the individual circuits as was the case in the early days of street-car motors when the field windings of the two motors were connected in parallel and the armatures in parallel. This particular form of connection was the cause of much grief from the unbalancing which resulted due to differences in the magnetic circuits, and provision had to be made for changing the air-gap or otherwise adjusting the individual motors so that they would divide their load properly.

As far as the motors themselves are concerned, there is very little additional complication from the necessity of interchangeability on different voltages. It simply requires the use of more armatures and at a greater cost than would otherwise be necessary. The motors, of course, would have to be insulated for the highest voltage on which they would be used. The complications introduced would be mainly in the control system, which is the next subject to be considered.

### (3) CONTROL.

Figs. 7, 8, 9, and 10 show the control diagrams and indicate to some extent the complications introduced by the use of several voltages. Fig. 7 shows a scheme of switches by which eight armatures may be operated, four in series and two series in parallel, two in series and four series in parallel, or all in parallel, corresponding to full speed on 2,400, 1,200, and 600 volts, or full speed on 4,800, 2,400, 1,200 and half speed on 600 volts. There are shown a total of 56 switches on this diagram, most of which would have to be designed and insulated to handle the maximum voltage. It indicates a comparatively complicated equipment in spite of the fact that the diagram is made up in its simplest form.

Fig. 8 shows the same number of motors arranged for operation on two voltages when connected permanently two in series. This reduces the number of switches to 36.

Fig. 9 shows the same number of armatures arranged for operation on a single high voltage. It is arranged for bridging control with the fields connected always to the earthed side of the motors and requires only 20 switches.

Fig. 10 shows the same number of motors arranged for the shunting transition with only 13 switches.

These diagrams serve to indicate the rate at which equipments are complicated by multiplying the number of voltages and combinations. It is, of course, unnecessary to use unit switches or contactors to effect all of these combinations. They may, to a certain extent, be made by means of cylindrical or drum-type change-over switches, which are satisfactory in some cases for transferring connections when the current is off. Such a scheme is usually used for car equipments operating interchangeably on 600 and 1,200 volts. This is shown on Fig. 11, which is a standard arrangement for such an equipment. It will be noted that the change-over switch changes both motors and resistances from series to parallel or vice versa. While such a scheme is quite satisfactory for lower voltages, especially for car equipments, it is generally considered to be better practice so to arrange the motor circuits of high-voltage equipment as to effect all changes possible by means of unit switches. All changes in voltage combinations can then be readily made by simply changing the control circuits.

The use of unit switches exclusively for making combinations in the main motor circuits is sometimes carried to the extent of using them for reversers as well, especially for large locomotives. This has the advantage of maximum reliability and the smallest number of types of apparatus for the equipment.

The diagrams which have been shown are for the plain series motors operating only as a motor without field control and without regeneration. The use of field control

NOTE.—The explanation of the symbols used in Figs. 7, 8, 9, 10, and 11 will be found in the Appendix to the Paper page 534.

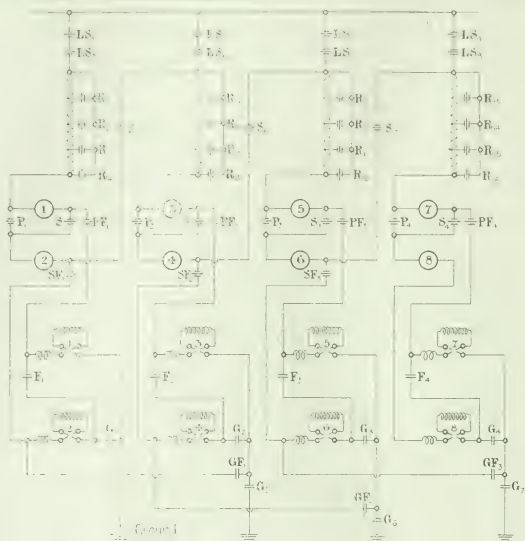


FIG. 7.—Diagram of connections of equipment for full-speed operation on three voltages, such as 600, 1,200, and 2,400.

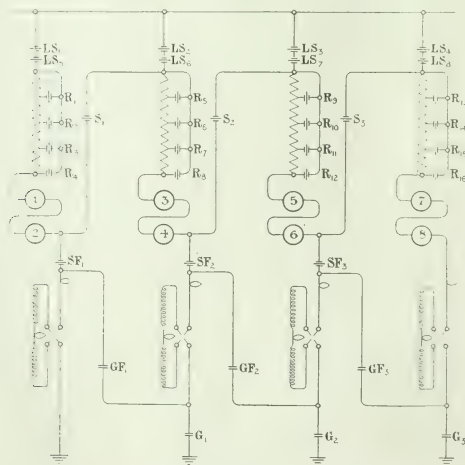


FIG. 8.—Diagram of connections of equipment for full-speed operation on 2,400 and 1,200 volts, and half speed on 600 volts.

usually involves the use of two additional switches for each motor where switches are used, unless two motors are connected permanently in series, when they can be controlled by the same number of switches as a single motor. Thus a 2-motor equipment on 600 volts can have the control equipments arranged for field control by the addition of two switches per motor, or a total of four switches for the equipment. A 4-motor equipment arranged for use with two motors connected permanently in series can also obtain the advantages of field control by a total of four switches; but if the four motors are ever to be operated in full parallel, eight switches will be necessary. Where eight motors are to be operated with field

motor circuits and for the operating circuits for the control. It is not assumed that the number of switches which have been given in the preceding diagrams is the exact number that will be required for any given case. They are simply typical and comparative diagrams. Undoubtedly many simplifications will suggest themselves to experts in control diagrams. In any case, however, the control circuits are apt to become very complicated where much change-over apparatus is required, and an increased number of train-line wires between the cars will be necessary for multiple-unit operation. It may be better imagined than described what the complication of an equipment would be to meet the requirements of three

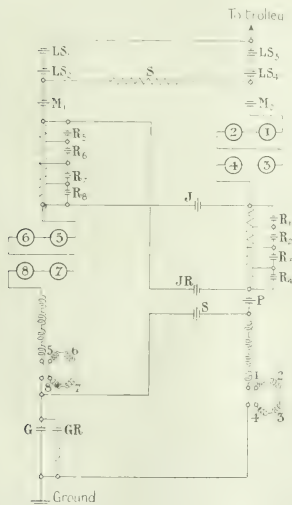


FIG. 6.—High-voltage equipment arranged for full-speed operation on one voltage.

control and arranged for full-speed operation on three voltages such as 600, 1,200, and 2,400, 16 switches will be required for a single step.

Much the same conditions prevail where the equipments are arranged for regenerative control. Where the motors are to be operated to give regeneration when connected all in parallel, it will be necessary to have a regulating apparatus for each motor, and consequently the additional control apparatus will be very considerable, requiring so much in fact as to make the regenerative control of very doubtful value.

It must be understood that each additional switch means additional wiring for the equipment, both for the main

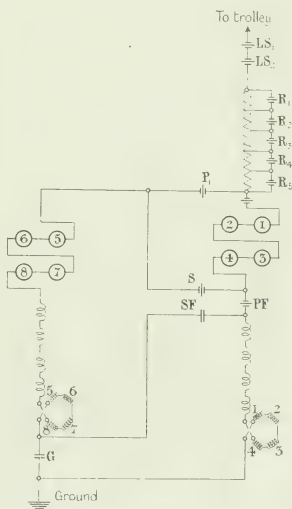


FIG. 10.—High-voltage equipment arranged for full-speed operation on one voltage, shunt control.

operating voltages and three forms of current collector. One of the worst examples of this sort of complication was found on the original Washington, Baltimore, and Annapolis equipments which were installed some years ago. The equipment was in the first place to be operated from a 6,600-volt single-phase trolley using a wheel trolley for collecting the current. It was also required to operate over a 600-volt continuous-current line; first, with single overhead trolley and earth return; second, with two overhead trolleys on a metallic circuit; third, on the underground conduit system. A more complicated equipment could not well be imagined and it is not to be wondered at that it was soon changed for an equipment operating at full

speed on 1,200 volts (continuous-current) instead of 6,600 volts (alternating current), and at half speed on the various 600-volt trolley systems. In this way all complications except those incident to the change in the collectors were avoided.

That it is perfectly practicable to operate complicated control systems satisfactorily and reliably is shown by such examples as that of the New York, New Haven, and Hartford alternating-current-continuous-current locomotives which operate both from a 11,000-volt single-phase trolley and from the under-running 600-volt continuous-current third-rail of the New York Central system. The author has seen many equipments operating on both alternating and continuous current and has no desire to see that method of operation extended, but the control

operating the switches governing the main circuits, but for controlling trolleys or contact shoes, lights, air compressors, signals, etc., the number of train-line wires even for a single operating voltage sometimes exceeds 20. Two or three operating voltages would therefore multiply the number of train-line multicore cables so that possibly two or three would be necessary to effect satisfactory operation, and these would have to be the same on all equipments if the cars were to operate interchangeably in the same train.

#### (4) AUXILIARY POWER EQUIPMENT.

Every electrical equipment has several auxiliaries which are usually supplied with power from the main supply circuit. On 600 volts the air-compressor motor, blower motor, if any, and lights are all supplied directly from the line. The power for the control circuit is also usually supplied from the line when electromagnetic contactors are used, but where the electro-pneumatic control system is used, the power for the control circuits may be supplied either from the main circuit or from a small storage battery. As the power for operating the magnet valves is so small and the advantages of a low-voltage train-line are so numerous, it is becoming more and more the practice to use a battery, especially on train service on elevated and subway lines where the battery performs the additional function of supplying power for emergency lights and signals.

The problem of supplying the power for auxiliary circuits on equipments receiving power at several different voltages is one of the most troublesome features to be considered. It is not particularly difficult where only two voltages are encountered, such as 600 and 1,200, which are very common in the United States. It has been common practice in such cases to use a dynamotor on the higher voltage to reduce the line voltage to half its value for the auxiliaries. Double-commutator auxiliary motors are sometimes used connected in series or parallel according as the line voltage is 1,200 or 600. In this case the control and lighting currents are taken from the low-voltage circuit. Single-commutator auxiliary motors are also sometimes used and run at half speed on 600 volts.

Any scheme involving operation over a wide range of voltage will necessarily complicate the equipment if it becomes necessary to operate continuously over any one of several line voltages. For the higher voltages it may be that the use of a storage battery, such as that provided on the 5,000-volt car equipment previously referred to, may prove to be the most satisfactory means. On this equipment a small-capacity storage battery to which all the auxiliaries are connected is included in the driving-motor circuit on the earthed side. The battery has capacity to operate the compressor, motor, lights, and control circuit for a limited length of time, but ordinarily these auxiliaries take most of their current from the main motor circuit. The compressor governors are so arranged as to delay the starting of the compressor motor until the car starts, instead of coming into operation immediately on the application of brakes, as is usual. The compressor and other auxiliaries thus simply shunt whatever portion of the main motor current is required, or all of it if necessary, and the battery receives or supplies the balance. The

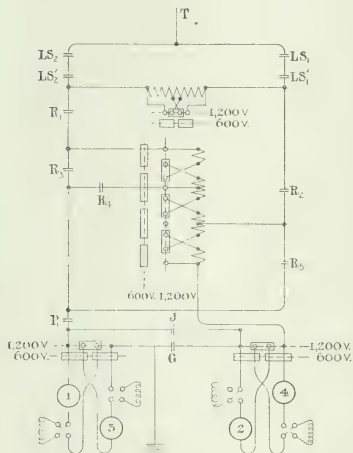


FIG. 11.—Diagram of main circuits for standard H. L. car equipment at 600 and 1,200 volts.

complications introduced by such an equipment are small compared with what would be involved in operating on three or four continuous-current voltages with full speed on three of them and with several different forms of contact devices. There is no doubt that the equipments can be arranged for successful operation in this way, but the additional first cost and the cost of maintenance would be so great as to be a serious handicap to electrical operation. It would be almost impossible in any case to operate equipments from all the different lines in the same multiple-unit train, since the difficulty of having the control interchangeable would be insurmountable. The simplest multiple-unit equipments require from 7 to 12 conductors in the train-line cable, and in view of the fact that it is becoming usual to have the train-line wires not only for

compressor can be so arranged that it will receive probably at least 90 per cent of its operating current directly from the main circuit without the current passing through the battery, which thus floats on the line and merely controls the voltage. The battery necessary for the car equipment is thus of comparatively small capacity. This system has the advantage of always maintaining practically the same voltage for the auxiliaries regardless of the voltage on the line. To avoid overcharging the battery on the low line voltages, the battery may be connected in series with a smaller number of motors. This is easily accomplished as there are several earth connections.

For locomotive use where the auxiliaries require considerably greater power it is quite feasible to use a motor-generator to supply power to the auxiliaries. The motor should be series wound so as to secure the greater stability due to that type of winding. In this case for supplying power from three voltages, such as 2,400, 1,200, and 600, two motors each wound for 1,200 volts could be used to drive a 600-volt generator, and be connected in series or parallel according as the line voltage was 2,400 or 12,000. When operating on 600 volts the motor-generator set would not be needed unless it were driving a blower, in which case the 600-volt generator could be used as a motor taking power from the line. Thus even in this case the problem has several solutions, any of which is perfectly practicable but more or less undesirable on account of the complications introduced. The great objection to this as well as in the remainder of the equipment to operating on several voltages, is the multiplicity of switches, change-overs, and main and control wiring and other details involved. It soon gets to the point where the ordinary car inspector cannot handle it.

#### CONCLUSION.

The logic of this paper points to the necessity for the early standardization of some of the more important features connected with electrification. The benefits of standardization would be immediately felt not only in the greater security of the railways in embarking on a project of electrification but in the decreased cost of all apparatus connected with it. If manufacturers could combine their efforts to the development of apparatus for one or two voltages rather than spreading them thinly over such a broad field, and could build enough apparatus of one type to put it on a manufacturing basis, the cost would be greatly reduced, the railways could save a large percentage of the present cost, and the manufacturer could also make a profit.

In a State with an autocratic government such matters could be decided by one man. In one with absolute individual freedom of action, every railway might have its own set of standards. Neither would be a satisfactory method to pursue, but of the two, the former would probably give the better results, since there would be at least interchangeability and the manufacturer of only one type of apparatus, even though it were not the best, would soon reduce the cost far beyond what would be possible under the other regime.

A better plan than either would be to secure the fullest co-operation of all concerned, carefully canvass the entire

subject, and make definite recommendations for standards. The initiative in such an important matter should be taken by the Institution, which numbers among its members all those who are necessary to decide such questions on their engineering merits. Its own prestige will go far towards making its recommendations into laws, but it would be well to secure the co-operation of all other organizations that are interested. Any committee in charge of this matter should include on its membership representatives of railway and manufacturing companies and consulting engineers. All must approach the subject with an open mind so as to determine as nearly as possible what will be the best for all, and their decision should be accepted as final. The author does not wish to be misunderstood as advocating that everything connected with electrification should be standardized either immediately or in the near future, but he feels that such things as the location of the contact rail for third-rail systems, and of a contact line for overhead systems, could be discussed and settled within a short time; also that the question of voltage can be considered and decided before any further railways are electrified or extensions made to existing continuous-current systems. The former is more especially a question for the railways themselves to decide and is simply a matter of the railway men "getting together"; but the latter is one for all engineers interested in electric railways, and although it is somewhat beyond the scope of this paper, the author will venture a suggestion concerning it.

Since the 600-volt system is so thoroughly established and also so well suited to the requirements of terminal electrification, it should be continued as one of the standards, at least for the present. While it is probable that but little will be done towards electrification of entire railway systems in the next few years, one other voltage should be selected that will be suitable for such service and will at least serve to direct the aim of those companies about to electrify. This voltage should be high enough to permit the heaviest drafts of power required to be collected from the overhead conductor without exceeding the capacity of a single wire or a single collector. It should be high enough to reduce the amount of copper in the feeder system to the lowest value consistent with reliable distribution. If motor-generator or rotary-converter sub-stations are used, the number should be reduced as far as possible so as to secure a good load factor and thus decrease the cost and improve the efficiency. In this connection it may be noted that if the vapour converter proves to be a commercial apparatus for such work, sub-stations may be placed economically at more frequent intervals. The determining factor in the entire question will of course be the cost, not only of the original installation but the cost of operation and maintenance. This will depend very largely on the electrical equipment of the locomotives and cars. It is obvious that the voltage will also depend on whether the equipments would be obliged to operate at full speed on 600 volts. If they are, it is practically useless to think of anything higher than 2,400 volts. This may possibly be high enough for the maximum trains in Great Britain, although it is not considered high enough in the United States, as is proved by the fact that the Chicago, Milwaukee, and St. Paul Railroad has adopted 3,000 volts for its extensive system after a short experi-

ence with 2,400 volts on the Butte, Anaconda, and Pacific Railway. In this case the service is so heavy, although by no means the maximum that will be required in America, that it is still necessary to use two trolley wires and a large amount of feeder copper. The author believes that a still higher voltage should be adopted if continuous current is to be used for trunk-line service with such heavy trains.

It is generally conceded that 1,500 volts is about the maximum voltage that can be economically used on the 4-pole railway motor. Even with that it is difficult to find space for the necessary number of commutator bars and brush holders, especially for small motors. It would therefore be necessary to connect more than two 4-pole motors permanently in series for operation with more than 3,000 volts. The type of motor used for the 5,000-volt equipment that has been mentioned previously, offers a solution

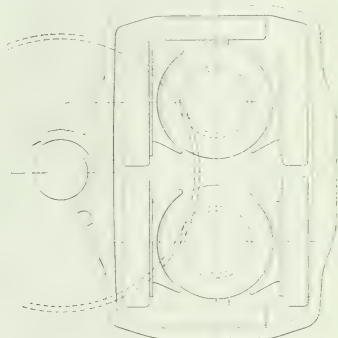


FIG. 12.—2,400-volt double-armature motor.

of the problem which makes a very considerable increase in line voltage appear not only possible but easy in so far as commutation and commutation bars are concerned. This equipment has been described in several of the American technical journals, but a brief description of the motor may not be out of place here as the construction is quite novel and has many advantages for high voltages.

Fig. 12 shows a diagrammatic arrangement of the armatures, poles, and magnetic circuit. It will be noted that there are two bi-polar armatures connected in series in each frame, and that the major part of the magnetic flux passes through the two armatures, their pole-pieces, and a short section of the yoke in series, which thus effects a great reduction in the weight of the material that would otherwise be necessary to secure the advantage of the bi-polar armatures. Each armature is wound for 1,250 volts, so that half of the line voltage is impressed on

each complete motor, as is usual with high-voltage equipments. So far as the commutators are concerned there appears to be no reason why considerably higher voltages should not be used if desirable. In fact the first two motors of this type were tested with 7,000 volts on the line, i.e. 3,500 volts on each motor, with very satisfactory commutation. The limit to the voltage will therefore be found elsewhere than in commutation. The question of insulating motor and control for such high voltages would also appear to be less serious than might have been expected. The sample equipment of four 100-h.p. motors has, up to the time of writing this paper, run over 15,000 miles in commercial service without a single defect in the high-voltage insulation, and the operation of the equipment has been highly satisfactory in every respect. It requires very little attention, as is evidenced by the fact that at one time it remained in service without inspection for  $9\frac{1}{2}$  consecutive days of  $19\frac{1}{2}$  hours each. At the end of that time it was withdrawn from service for reasons entirely apart from the equipment or power supply.

While this development has thus far not been carried far enough to prove the entire success of the 5,000-volt continuous-current system, it at least offers to those who desire a high continuous-current voltage good ground for hoping for the realization of their wishes.

The author suggests that if possible the "through" lines should be differentiated from the purely suburban lines, and that the best voltage for the former should be adopted regardless of the latter; that an overhead contact wire in addition to the 600-volt third rail be placed over each track that requires full-speed operation for both equipments. While such a scheme has its disadvantages, they are negligible compared with the complication of equipments necessitated by the interchangeable operation on several different voltages.

## APPENDIX.

EXPLANATION OF SYMBOLS, ETC., USED IN FIGS. 7, 8, 9, 10, AND 11.

- ≡ Double-break switch.
- LS Line switch between collector and motor.
- S Armature series connection switch.
- SF Field series connection switch.
- F Field switch.
- G F Field earthing switch.
- Armature.
- Commutating pole.
- ≡ Single-break switch.
- R Resistance short-circuiting switch.
- P Armature paralleling switch.
- PF Field paralleling switch.
- G Earthing switch.
- J Bridging control switch.
- Field winding.
- Reverser.

DISCUSSION BEFORE THE INSTITUTION, 16 MARCH, 1916.

Mr. C. H. MERZ: The author refers to what has been done with extra high voltage, and the idea of the double-armature motor is, I presume, largely, if not entirely, due to him. The great advantages which it possesses from the point of view of high-voltage working are obvious. The fact that it has not only been developed but applied to service so quickly is characteristic of American practice. It is extraordinary, when one considers the advantages of regeneration from the point of view of wear and tear of rolling stock, brake equipment, rails, etc., that more has not been done with it in all countries. Until quite recently I suppose the only place where it has been extensively used is in connection with 3-phase work in Italy and Switzerland, where it has been proved to be a great success and of considerable commercial advantage. The *Giovi* line is, I think, one of the best examples of that kind. Regeneration has been greatly simplified, from the point of view of continuous-current working, by the development of commutating-pole motors, but in this country there is no instance of its use on stopping services, although we have now a great deal of suburban work (on which regeneration ought to be particularly useful). The use of a high voltage should, I think, simplify its trial and adoption, because in such instances a dynamotor or similar apparatus is essential for supplying current for the control circuits, lighting, compressors, etc., and that piece of apparatus can be economically used for so exciting the fields of the series motors in different combinations as to obtain regeneration; for I agree with the author that the series motor is not likely to be abandoned, and with high voltages and dynamotors or motor-generators I do not see that this should be necessary. The concluding theme of the paper is perhaps the most interesting. The author there in effect urges us to standardize our voltage without delay. I think most people would admit that a third rail at 600 volts must be taken as one standard, in view of the large and increasing use of this system in the neighbourhood of London. We must also have a standard at higher pressure, since we cannot do everything at 600 volts. I believe that before many years have passed there will be a large amount of electric railway work in this country. Anyone who has taken out statistics of the traffic on our various lines need not go very far in his calculations to prove that there is a very great advantage in handling our very dense traffic electrically, and particularly goods traffic. If we are to handle the main-line goods traffic electrically between large industrial centres, a higher voltage than 600 will certainly be necessary. Having said that, however, I think the matter is not quite so simple as the author suggests. To begin with, it cannot yet be stated positively whether the third rail or the overhead wire is going to be more generally adopted for main-line work in this country. In the United States the distances are so long and the traffic is, comparatively speaking, so much less dense, that to carry out electrification economically it is necessary to adopt fairly high voltages. A pressure of 3,000 volts has now been adopted on a very large scale, and reference is made in the paper to the use of 5,000 volts. I suppose they will eventually have a standard voltage of certainly not less

than 3,000 for main-line work. But 3,000 volts could not be used with a third rail—certainly not in this country, where the clearances between the rolling stock and the structure gauge are very small. I think the question of whether a third rail or an overhead wire will be adopted for standard main-line work in this country will have to be determined before we can expect finally to standardize a higher voltage. If the third rail is not going to be adopted for main-line work except in very special instances, it would certainly be advisable to choose a higher upper standard than would be possible if we were going to take for that upper standard a voltage that would be suitable for third-rail work. As is now generally known, the Lancashire and Yorkshire Railway are either just starting up or have started up a third-rail system at 1,200 volts, and so far I believe it has run with remarkable success. It has the great advantage that the pressure chosen is exactly double 600 volts, and if it were generally adopted it would no doubt be possible to use the same design of third rail up to say 1,500 volts, so that 1,500 volts in that case would be a very good upper standard and would admit of overhead-line work at the same voltage. If on the other hand we are to do without third-rail working altogether, it is perhaps doubtful whether 1,500 volts is quite high enough for overhead-line main-line work for the country as a whole. While, therefore, I quite appreciate what the author says about the benefits of standardization, and feel that from a manufacturing point of view it is much to be desired, I doubt whether we should really hasten it in this country by attempting at the present moment finally to state whether we require for our upper standard pressure 1,200 or 1,500 volts or some such figure, or alternatively 3,000 volts or some such figure.

Mr. R. T. SMITH: Referring to a paper which I read before the Institution two years ago\* in which the performance of electric locomotives fitted with series motors was compared with that of steam locomotives, the author says that I did not do justice to the former. I should like to point out that my criticism was exclusively confined to fast passenger services with train loads on British railways and entirely under British conditions. Under these conditions, and these conditions only, I said that no electric locomotive had then been built anywhere which, between speeds of 70 and 80 m.p.h., could develop 1,100 h.p., which was being developed every day by steam locomotives employed in fast passenger service in this country. The author shows on page 523 that the Pennsylvania 4—4 + 4—4 articulated locomotive, which I believe weighs 140 tons, can develop 1,200 h.p. at 76 m.p.h. Fig. A, prepared from Fig. 3, gives the tractive characteristics of that Pennsylvania locomotive. One curve with normal field and the other with full field show the tractive effort of the locomotive plotted against speed. The tractive effort at the rims of the wheels includes the force needed to propel the locomotive. Against it, and to the same scale, I have shown the draw-bar pull of a Great Western Railway 4—6—0 steam passenger locomotive using only saturated steam. The draw-bar pull excludes

\* *Journal I.E.E.*, vol. 52, p. 293, 1914.

Mr. Smith. the force needed to propel the locomotive. The characteristic of the steam locomotive is such that from about 15 m.p.h. up to 80 m.p.h. the engine gives practically constant output. The steam locomotive weighs 75 tons, and the electric locomotive 140 tons. In order to develop the same power as the steam locomotive at a speed of 76 m.p.h. the electric locomotive must, at low speeds, be able to develop 4,000 h.p., and, what is worse, we have to pay for that ability. The electric locomotive, in order to do what steam locomotives are doing every day on the Great Western Railway, must weigh nearly

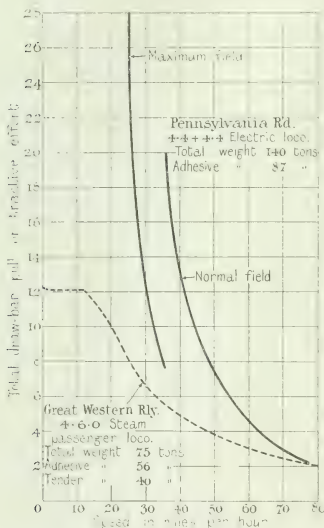


FIG. A.—Curves of draw-bar pull (steam loco.) and tractive effort at wheel-roads (electric loco.) plotted against speed.

twice as much and cost nearer to four times than three times the cost of the steam locomotive. That is the reason for my criticism. What I stated in 1914 was not strictly true. An electric locomotive had been built to equal the steam locomotive at top speed, but in order to achieve this result, its size and cost are out of all proportion to its steam rival. I want to emphasize again that these criticisms of the series-motor characteristics for electric locomotives apply to fast passenger service only. For goods and for mineral working the series characteristic is satisfactory where it is unnecessary to go to high speeds. In the first section of the paper the author admirably defends the qualities of the series motor. The first great improvement to the plain series motor that the author

notes is that of field control, which has been made possible by the commutating pole. The second great improvement is regenerative control, which has been fully touched upon by Mr. Merz. Unfortunately we have as yet no particulars of the method used by the Westinghouse Company, but I understand that what the author claims in the paper has been very amply justified by the experimental results so far obtained. From the railway point of view, and looking not only to suburban working but beyond that to goods and mineral haulage by electric locomotives, which I personally believe to be the most useful immediate field for electric traction, field control, together with regenerative control where the latter is required, seem to be the additional features needed to enable the series motor to do what railway people require of it. For a 4-motor equipment the author has shown that eight switches are essential for field control; we do not know how many switches are necessary for regenerative control, but the two together cannot demand much less than 20 switches. It should be borne in mind that if we believe in these two features we must have, apart from the switches needed for series-parallel control and for any change in pressure, at least 20 switches. I quite agree with Mr. Merz that we are not yet in a position to agree what our standard high pressure ought to be. For suburban and branch-line working, in addition to the almost universal use of 600 volts, a pressure of 3,600 volts is in use on the Lancashire and Yorkshire line between Bury and Holcombe Brook, 1,500 volts on the North-Eastern Railway between Sheldon and Newport for a purely mineral line, and, again on the Lancashire and Yorkshire, 1,200 volts between Manchester and Bury. Mr. Aspinall's 1,200-volt protected third rail, referred to by Mr. Merz, is, I am glad to say, quite satisfactory. I saw it only a little time ago, and it has worked without a hitch from the start, and, what is more important, under the recent conditions of heavy snow it behaved quite admirably. The snow formed an arch over the slot in which the collector works (the collector being a flat plate), protecting the vertical face of the third rail from which collection takes place and keeping it quite dry. There was not the least difficulty in the collector discharging all the snow. Engineers are grateful to such railways as have had the courage to make experiments with higher pressures than 600. I want to emphasize the fact, in connection with the various pressures discussed in the paper, that the pressures other than 600 adopted in this country are only experiments, and that nothing has yet been done which commits us to any single voltage other than for suburban working, which is really a thing apart. In the last paragraph of the paper the author summarizes admirably the problem that will have at some time to be solved in this country. If I may venture to re-state his summary in my own words, it would be that we have got to choose the most convenient pressure for suburban working by a third rail. If lines cannot be set apart wholly for this suburban working, we have then got to choose the best pressure for main-line working by overhead conductors and to equip the line with both where it is necessary. The author clearly shows the penalty that railways will have to pay if they do not choose one or at most two pressures, and it is the duty of railway and electrical engineers to see that the railways do not fall into

this mistake. As Mr. Merz has said, there is not the least reason why Mr. Aspinall's protected third rail should not be used for 1,500 volts, and it is quite certain that on electrified lines in manufacturing districts, where the atmosphere is very impure and charged with chemicals, and also in places where there are considerable lengths or numbers of low-roofed tunnels, a third rail is absolutely necessary. Let us assume, for the moment, that 3,000 volts is a satisfactory higher pressure to be used throughout this country with an overhead conductor. If 1,500-volt motors are employed, a third rail at 1,500 volts can work in with the higher voltage, and full speed and full power be obtained with equipments working with both voltages. This result can be obtained with the least amount of switchgear additional to that needed for those other features which are more or less essential—regenerative control and field control. I hope that the extra switchgear required for working with two voltages will not prove too complicated for use with electric locomotives in this country. All railways, as well as the Institution, are grateful to the author for pointing out so clearly just the sort of troubles that are going to arise if, when the proper time comes, we cannot agree what the value of the upper pressure should be.

Mr. F. LYDALL : I should like first to refer to the question of field control. One point of view might be mentioned which is rather different from that put forward by the author. He raises the question as to what range of speed can be obtained at constant output. Perhaps a more useful method of looking at it would be to ask what range of speed can be obtained with a constant tractive effort, or, better still, what range of balancing speed can be obtained by the use of field control. By "balancing speed" I mean the speed of a certain weight of train on the level, neither accelerating nor retarding. I have worked out from the speed curves given in the paper for the Pennsylvania locomotive a few figures which may be of interest from this point of view. I took first of all the higher speeds, namely, those given for 1,200 h.p. constant output, and I assumed a 900-ton train. The figures were as follows :—The variation of speed for the 1,200 h.p. constant output is from 42 to 76 m.p.h., that is to say, an increase on the lower speed of 80 per cent. Taking a constant tractive effort of 10,000 lb., which corresponds to 1,200 h.p. at 42 m.p.h., I only obtained an increase from 42 to 60 m.p.h., which is 42 per cent. Further, the balancing speed for this 900-ton train is raised only from 42 to 54 m.p.h., that is to say, 28 per cent. This contrasts with the figure mentioned for constant output, viz. 42 to 76 m.p.h., i.e. an increase of 80 per cent. In order to consider the question from another aspect, I took 1,600 h.p. output, and the figures corresponding to that are as follows :—36 to 60 m.p.h. speed variation for constant output, or only 66 per cent, whereas with a tractive effort of 16,700 lb. the increase was only from 36 to 49 m.p.h., or only 36 per cent. For a 1,670-ton train on the level, the increase in speed was only from 36 to 46 m.p.h., or 28 per cent. I might also mention corresponding figures for a locomotive which is not in existence, and very likely never will be. This is a locomotive the design of which I have worked out in some detail. It is a 3,000-h.p., 1,500-volt locomotive, and instead of having 50 per cent field-shunting, as I believe to be the case with the Penn-

sylvia locomotive, it has only 40 per cent. The cor- Mr. Lydall. responding figures in this case are as follows :—Constant output of 1,800 h.p.; speed 63 to 90 m.p.h.; 11,000 lb. tractive effort at 63 to 78 m.p.h., or, with a 500-ton train, 63 to 74 m.p.h., the last increase being only 17 per cent. I should like to refer to these various figures, comparing the high-voltage locomotive with the 600-volt locomotive of the Pennsylvania Railroad, and noticing once more that the Pennsylvania locomotives have a field variation of 50 per cent, whereas in the other case it is only 40 per cent, while the increase in the balancing speed for the Pennsylvania locomotive is 28 per cent, as against only 17 per cent for the high-voltage locomotive. When I noticed that in the one case the increased balancing speed was not nearly as great as in the other, I began to think that possibly the motor which I had worked out was not designed on the best lines, because the variation was very much less; but on further consideration I came to the conclusion (I only put it forward tentatively) that for a higher voltage, viz. 1,500 volts, it was not so easy to produce a steep characteristic speed curve as it is for a 600-volt motor. The reason for that to my mind is this, that with a higher voltage motor it is necessary to have a considerable pole span in order to get in the necessary commutator segments between the brushes, and that in itself necessitates considerable saturation in order to avoid excessive distortion and consequent tendency to flash-over at the brushes. I do not know whether the author can say anything on that point; it would certainly be interesting if he could. The general discussion as to the most favourable line voltage is interesting, but it seems to be rather by way of pointing out to railway and electrical engineers the troubles which are likely to be experienced on a very serious scale unless some steps are very soon taken. Already in this country there are several voltages which must be taken into account; they have been enumerated by Mr. Merz and by Mr. Roger Smith. But there is one voltage which has not, I think, been mentioned or considered—I mean the voltage of the single-phase line on the London, Brighton, and South Coast Railway. If an endeavour is to be made to produce interchangeability of traffic all over the country, this voltage must be taken into account. And when we consider that, we can see that if the author cared to do so he could put up a most terrifying proposition. Let me suggest the following condition, which I may call a climax of undesirability :—The locomotive to be suitable for running at full speed at 600 volts with a third-rail collection, and at 1,500 volts, and also on 6,000 volts single-phase with overhead collection; field control in the case of both continuous-current systems, and regeneration on all three. I regret that the author has given practically no information about the question of cost. It varies considerably with the voltage adopted. In considering what is the most suitable voltage to standardize, if it must be standardized, perhaps the most important consideration is what would be the cost, or rather by what percentage would the cost be affected by raising the voltage. Theoretically, if any particular electrification case is considered purely on its merits, and without reference to whether the electrified section is going to be extended or whether the traffic on that electrified section has ultimately to run over some other section, then it is necessary to try and arrive at a

Mr. Lydall. balance between the saving in the cost of copper on the feeder system and on the overhead line or other distribution system, and the extra cost of the rolling stock involved by raising the voltage. It is fairly easy to estimate what the saving of copper will be in any particular case; it is a matter more of calculation than of experience, I suppose; but I believe there is very little information available in regard to what the increased cost of the equipment would be. It is rather too much to expect the author to give much information on that point, because if any is available it is very much the property of manufacturing companies. I should also like to make another suggestion for the author to criticize. This time it is a comparison between a 1,500-volt motor, wound and insulated only for 1,500 volts, and a motor of the same rating, say, 375 h.p., insulated for 3,000 volts. We have got to provide much more insulation in the armature windings, much longer insulation at the straight part of the end windings, and also much greater leakage surfaces at both ends of the commutator. The result inevitably is a considerably larger motor. In the particular case of the 375-h.p. machine, the increase in the D<sup>2</sup> L of the motor was 40 per cent. I do not suggest that this is going to represent entirely the increased cost of the motor; it may or may not; I think it is quite unlikely it will be so much. Then there are the other parts of the equipment. A 1,500-volt compressor motor is quite practicable, but I think there is no question that it would not be satisfactory to try and drive the compressor direct off a 3,000-volt supply. That is to say, there must be a considerable jump in the size of the dynamotor or other converter used to supply the current to the auxiliary circuits including the compressor motor. All the other equipment details want a great deal of working out. The final result certainly will be that the total cost of the equipment will be very substantially greater for 3,000 volts than for 1,500 volts. The author has also put forward the suggestion that the Institution should take a hand in the solution of the problem as to what should be the standard voltage for the whole country. I think it is a very difficult thing indeed to determine the exact time when standardization should take place. The first question that arises is whether there is sufficient information available for a committee to reach any definite conclusion. For my own part, I feel confident there is not. I do not think railway engineers in this country are ready to supply all the necessary data to such a committee, without which it would be absolutely impossible to come to a conclusion. I think it is necessary at the present time that railway engineers as a body should be convinced by experiment throughout the country that long-distance traffic by electrical means for goods or passenger service is practicable and more economical than haulage by steam locomotives.

Mr. Firth. Mr. H. W. FIRTH: The author has considered two very important points, viz. the speed characteristic of the ordinary series motor, and the present wasteful method of accelerating and retarding; and he has expressed the hope that in both those respects motor designers will be able to assist railway men in obtaining a material improvement. Regarding regenerative braking, I should like to ask the author to make it quite clear that he is hopeful of its being applied to multiple-unit equipment. If the figures given by the author are achieved in practice, and if there are no countervailing drawbacks, I think it is

undoubtedly the case that a considerable improvement in the economic possibilities of electric traction is within sight. With regard to the question of standard voltage, I think one point must be particularly emphasized, namely, that we must do nothing whatever which will militate against the universal interchange of, at any rate, main-line equipment, whether this does or does not consist of locomotives. The war has shown the importance of the facility with which the locomotives of one railway company have circulated freely on the lines of all the other companies. To my mind it is not satisfactory to say that we must have a standard main-line voltage and a standard suburban voltage, and that there the line of demarcation will cease. In my opinion not only must the main-line equipment of one railway be interchangeable with that of another railway, but it must be capable of running on the suburban voltage of its own or any other railway. Around London, and probably around many other places, there are connecting lines between important main lines. These connections are very largely suburban passenger-carrying lines; but in times of emergency such as the present, and also for goods working in normal times, those lines are used by the present goods and main-line locomotives. Therefore I think the author's suggestion that we may have a separate main-line conductor into a terminus and also a separate lower-voltage conductor for suburban working is not one which would commend itself to railway engineers. Further, from the general point of view, although in some cases at any rate it is quite possible—and of course it is always desirable—to separate main-line working from suburban working, in a great many cases it is not a matter of practical politics. If one cannot do so, it means that one must equip a very large portion of the terminal area, at any rate, on both systems. The paper has done a great deal of good in one respect, in that it has shown us what an ingenious designer can do with complicated switchgear if it is necessary to work at varying voltages, and I am glad to see the author deprecates going in for any considerable number of the possibilities which one can get with this varying switching. Previous speakers appear to have agreed with the contention of the author that we are committed for all time to a pressure of about 600 volts for heavy suburban work, but I would suggest that very serious considerations should be given before we assume that we are tied down to that voltage. It is certainly the popular one; and it is the one which has been used so far, with the exception of the Lancashire and Yorkshire line from Manchester to Bury. Considering that this pressure practically limits us to 1,200 volts for our upper limit of voltage if we are to get a really satisfactory arrangement, I suggest that great hesitation should be shown before assuming that a standard of 600 volts has to be retained. I suggest that, if we are to have two standard voltages, the whole matter should be reconsidered. If it is necessary, in the broad interests of the whole of the main-line and goods working in this country, to change that 600 volts over to 1,200 volts or 1,500 volts, so that we can adopt anything up to 4,800 volts for pure main-line working if desired, I suggest it would be worth while to consider the question on its merits, in spite of there being a large amount of 600-volt track in operation. The Manchester experiment on the Lancashire and Yorkshire Railway appears, from what

Mr. Roger Smith says, to be, so far as can be seen, highly satisfactory, and if that be so I see no reason why, in the course of time, 1,200 volts should not be adopted, not for our upper standard but for our lower standard. On the question of whether it is possible at the present time to standardize a definite main-line voltage, I agree with the previous speakers that the time is hardly ripe.

Dr. S. P. SMITH: The author has drawn our attention to the broader outlook of the continuous-current system with regard to the extension of field control and regeneration. He refers to the series motor and deals with its characteristics, showing that it is the best motor for the work it has to do. A further illustration of its suitability for traction work has been given during the last few days, when, owing to ice and snow on the rails, the contact has been very bad on several occasions. With regard to the use of the series motor for large outputs on locomotives, I do not know that the author has given us sufficient information to prove its suitability, and I join with Mr. Roger Smith and Mr. Lydall in asking if he can make the matter somewhat clearer. Mr. Roger Smith showed that the series motor must have very large outputs at low speeds in order to give the required output at high speeds. Field control will not, I am afraid, help us much on main-line work, for weakening the flux reduces the torque. It is rather voltage control that is needed to give the large outputs at high speeds. For this purpose, series-parallel control is not sufficient, and it almost looks as if we must have a motor with the characteristics of the alternating-current motor. Some members may recall the speed curves of the single-phase 15-cycle Löttschberg locomotives that were published a year or two ago. With those locomotives it is possible to get, instead of two or three curves, quite a family of curves, which will give us almost any power at any desired speed within the working range of the motor. It seems that motors for main-line working will have to be considered from this wider aspect, and in my opinion the paper does not show that the continuous-current series motor is going to solve the problem; the single-phase series motor may be better adapted to solve some of the difficulties to which Mr. Roger Smith drew attention. I desire to ask one question in regard to regeneration. It is very satisfactory to have the author's authoritative figures as to the improvement that can be expected with field control and regeneration: the former halves the rheostat losses, whilst the latter reduces the energy consumption by some 20 per cent. When we remember that the cost of energy may be something like half the working costs, any saving whatever is important, so that a reduction of 20 per cent means a great deal. But there is one question about regeneration which I should like to ask. One does not doubt for a moment that it is possible to obtain regeneration theoretically, but the practical solution may be difficult. Modern traction motors have very small clearances, being almost as large as possible for the space available under the coach. What are we to do, therefore, when we have regeneration? We must remember that when a machine regenerates it works as a generator and develops heat all the time. At present the motor can do its work because it gets a period of rest during the braking, but if we are going to make it work also during that time, how are we going to keep it cool? Does the author pro-

pose to adopt forced ventilation? We cannot use a larger motor, for the space is already fully utilized; hence if we are going to get more out of the machine by making it act also as a generator we must get rid of that extra heat, unless the life of the motor is to be shortened. I should like to know what the author proposes. With regard to locomotives, regeneration will probably not be of much use except from the point of view of the saving in tyres, brake blocks, etc., because it is useless to send the energy back to a station where it may not be wanted, as there may not be another locomotive requiring it. In many of the systems on the Continent where regeneration is adopted, the returned energy has to be wasted in water resistances at the station, or in some other way. Where the traffic is dense, as on suburban lines, we can always make use of any energy available, but if the traffic is sparse, the regenerated energy may be troublesome. The last point I want to mention is the question of voltages. A railway man recently told me that the author's object appeared to be to frighten engineers against using two, three, or four voltages. He certainly has done that very effectively. In America it is or was by no means uncommon to find an alternating-current and a continuous-current system working in conjunction, and the experience of the American engineers is probably by no means a happy one in regard to the use of different voltages and different systems. It seems to me that in the last paragraph of the paper, where the author states that there are many advantages in having the main-line voltage and the suburban voltage quite independent, he solves the problem in a way which will appeal to British engineers. The third rail for the suburban traffic and the overhead system (with either high-tension continuous current or single-phase alternating current) for main-line traffic can be kept quite independent—the running rails acting as the common return if need be. I think two independent voltages and systems will appeal more to British engineers than any of the complicated methods the author discusses where the same motors have to work on two or more voltages. It will also solve the problem of goods yards, etc., where locomotives and overhead equipment are essential.

Mr. H. M. SAYERS: The subject of regeneration by traction motors has been under consideration by engineers for a very long time. The experimental work done in this country on the subject has mostly been in connection with tramways. Dr. Smith has just mentioned one of the reasons of failure, namely, that a motor which has to act as a generator whilst braking and as a motor whilst propelling has no time to become cool, with the result that it either gets overheated or must be a large motor for its output. Limitations of space in regard to motor capacity are quite as severely felt on tramways as on railways, and that particular trouble was a serious one on some of the hilly lines where Mr. Raworth's regenerative motors were tried. The more general reason is that a regenerative motor requires to have a shunt characteristic. Whether this characteristic is got by using a shunt winding, or by field control, or by separate excitation, it is essential if the motor is to regenerate successfully. A motor having a shunt characteristic, as the author states, is not suitable for acceleration in the way in which we use motors to-day for traction purposes. I should like, however, to suggest that

Dr. Smith,

Mr. Sayers.

Mr. Sayers. a motor having a shunt characteristic can be used as a variable-speed motor by introducing between the motor and the wheels of the locomotive or car a speed-torque gear of a satisfactory character. Such a speed gear as is used on motor-cars is obviously out of the question, but there are one or two speed gears now in use, such as the Hele-Shaw and the Williams-Janney, which appear to be very promising in that connection. If such a gear were used, none of the weight of the motor need be carried on the axles, and the reduction of unsprung weight on the axles would be of considerable importance from the point of view of the wear of wheels, bearings, rails, etc. That appears to me to be a point well worth consideration when dealing with the question of regenerative control and with other problems that arise in main-line working, especially with heavy trains on steep gradients.

Mr. Dover. Mr. A. DOVER (*communicated*): In connection with the author's concluding remarks—which refer principally to the standardization of line voltage—it is interesting to observe that the universal adoption of field control will tend towards the standardization of car equipments, since this system of control allows motor-cars with a given equipment to be operated economically on different services. Thus one class of motor and gear-ratio could be used for operating either on city service (with, say, two stops per mile; schedule speed, 16 m.p.h.) or on fast suburban service (with, say, two miles between stops; schedule speed, 33 m.p.h.); whereas, without field control these services would require equipments with different gear ratios, and interchangeability of the motor-cars would not be possible. The provision of two tappings in the field winding gives a very flexible motor equipment for motor-cars, as, with series-parallel control, six economical speeds are provided for a given motor current. Thus, as far as speed regulation is concerned, the field-control continuous-current motor is, for motor-car operation, practically on an equality with the single-phase motor. Moreover, the sustained acceleration with field-control equipments compares very favourably with that obtained with single-phase equipments. Comparisons between the weights of field-control and non-field-control motors should be considered with reference to service capacity and energy consumption rather than the rated load of the motors. The author shows on page 525 that the field-control motor, in virtue of its lower R.M.S. current, will have a higher service capacity than the non-field-control motor of equivalent (1-hour) rating; but the ratio of the service capacities of these motors will be greater than the ratio of the R.M.S. currents, since the core loss, during speed-curve running and free running, will be lower in the former motor than in the latter machine. Moreover, since the field-control motor would probably be geared for a lower armature speed—corresponding to a given car speed—than the non-field-control motor, the former motor would have the lower friction and gear losses at free-running speed. Thus, when the difference in the rheostatic losses is considered, the balance will be considerably in favour of the field-control motor. With reference to the author's remarks on the regenerative control system in course of development, it would be of interest to know whether or not provision has been made for eliminating the rheostatic losses during the accelerating period. In connection with this system of control, it is

interesting to note that an overall efficiency of 80 per cent (or more) is anticipated. Obviously, the efficiency during recuperation is an important feature in all successful regenerative schemes. The difference between the excellent results obtained with 3-phase multi-speed equipments and the inferior results obtained with single-phase equipments, is entirely due to the low overall efficiency of the latter equipments.

Mr. J. WARREN (*communicated*): The author, in dealing with the question of standardization of pressure for the electrical operation of British railways, naturally finds considerable difficulty in reconciling the continuous-current working pressure of 600 volts, and rail conductors adopted for the suburban lines of some of the British main-line railways, with the higher pressures with overhead conductors which he evidently considers to be essential for general requirements on these railways. The suggestions made for overcoming the difficulty are divided into two methods of compromise: first, the adoption of a standard pressure which is a multiple of 600 volts, with a maximum of 2,400 volts for general main-line working; and secondly the adoption of two standard pressures, one to be 600 volts for suburban working and the other some higher pressure for main-line working, which higher pressure would presumably be decided upon when the maximum has been determined by experiment. The first method would fix the maximum standard pressure at a limit which the author does not consider to be the best possible for general requirements, and would at the same time introduce much complication, with consequent additional cost (both capital and working). The second method, although probably the better solution of the two, would only attain the object of pressure standardization, namely the interchangeability of rolling stock and locomotives, to a limited degree as compared with steam working, and would further involve the equipment of all suburban lines with a dual conductor system so as to allow goods and main-line trains being worked over them. The additional capital cost of such a scheme would hardly seem to recommend it. A very important fact, which must be remembered in considering any suggestions for fixing a high-pressure standard for continuous-current working, is that this high pressure is impressed directly on the motors, and despite the various ingenious methods adopted and proposed by the author and others for distributing the pressure over several commutators, the high pressure to earth always remains; precautions, which increase the cost and weight of the equipments, have therefore to be taken in a degree proportional to the raising of the pressure. The author deals only with the continuous-current system in discussing standardization of pressure, but it should be pointed out that with the adoption of the single-phase alternating-current system practically all the difficulties in this connection to which he alludes disappear. Granted an overhead conductor system for high pressure, whether continuous or alternating current, the practicable economic limits of pressure for the single-phase alternating-current system are already known and a standard could be fixed without waiting for further experiment; and whatever standard of line pressure be adopted, the pressure to earth on the motors remains the same, the same remark also applying to auxiliary motors and lighting as well as to the control system. The fact

en. that a high-pressure single-phase alternating-current system can be satisfactorily employed for suburban working on a main-line railway in this country has already been demonstrated.

Mr. E. V. PANNELL (*communicated*): This paper is of particular value because it deals with our British electric railway problems from the view-point of an American engineer who is unbiased and unhampered by our insular conventions. The characteristics of the motors shown in Fig. 1 (these motors appear to be rated at 250 h.p. and not 200 h.p. as stated) illustrate very clearly the effect of high saturation. Not only does this bring about the disadvantages mentioned by the author, but it renders the core loss of the motor disproportionately high and predicates an excessive weight of field copper. To estimate approximately the degree of saturation in any railway motor, I usually divide the speed at one-third rated load by the rated load speed. This quotient is quite an arbitrary

engineer will be able to calculate his train schedules on Mr. Pannell's the normal-field running, thus leaving the short-field connection as a reserve for making up lost time. Although almost a matter of common knowledge, it might perhaps be mentioned that the gear ratio has a similar, and just as important, influence upon economical operation as the degree of saturation. A motor geared for too high a speed will take a longer time for its initial acceleration, thus giving rise to higher rheostat losses, and will also take a higher R.M.S. current for a given run. In fact the disadvantages of excessive saturation can be very largely offset by the choice of a sufficiently low speed gear ratio. Turning to the matter of higher voltage operation, I do not feel at all sanguine in regard to the operation of four 750-volt motors in series on 3,000 volts, because should one pair of wheels slip, a bad flash-over could not be avoided. Two motors permanently in series is as far as one would care to go, and in view of the possibility of a perfectly

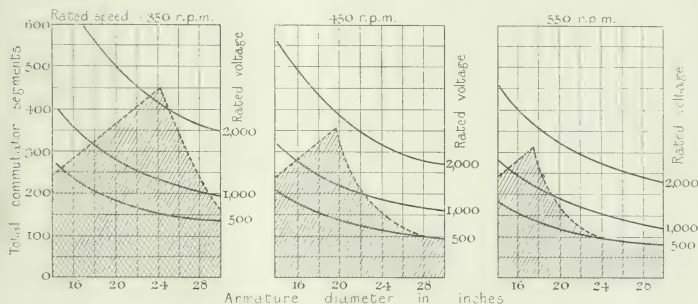


FIG. B.

quantity except that it takes in what are usually the maximum and minimum service speeds with the motor running directly on the line. This ratio I term the "saturation factor" (which is, however, not a very good term), and as will be seen from Table 3 of my recent paper\* it averages about 1.75 to 1.80 for modern designs of motors for suburban service. Working out this factor from Fig. 1 of the present paper it is found to be 1.82 for the unsaturated motor and 1.50 for the saturated design. The former is therefore quite a typical machine; the latter, owing to its excessive saturation, is not. Where it is desired to make use of field control, however, this is just the type of highly-saturated flat speed curve that is necessary, otherwise the flux densities would be very low and the speeds dangerously high when the field is weakened. Field regulation gives the motor two or more distinct characteristics, in other words two speeds for every value of drawbar pull, and with further development the flexibility of electric motor operation should be sufficiently marked to compare much more favourably with the steam locomotive at high speeds. Where field-control motors are employed, the railway

satisfactory design for a 1,500-volt motor, a greater number in series is not necessary. The interesting twin-armature motor described in the paper would seem to be better adapted for locomotive than for motor-car operation, as it would be difficult to obtain sufficient room for the two armatures under a standard type of railway car. With wheels of about 40-in. diameter the armatures can hardly be larger than 12 in., whereas in modern high-voltage motors of heavy output 20 in. or more is usual. The main difficulty in high-voltage motor design is in finding sufficient space for the commutator. Fig. B herewith was prepared to illustrate this point. The curves are based on the following conclusions: any given size of railway motor carcase is capable of carrying a given flux, consequently for a certain voltage the number of turns on the armature will decrease with increasing dimensions owing to the increased flux per pole. Now as all large railway motors have only one turn per segment we may say that the number of segments decreases with increasing diameter of armature. This is shown by the drooping full curves in the diagram. The two limiting features are the minimum practicable width of segment and the maximum desirable

\* See page 449.

Mr. Fannell. average voltage per segment. The former has been taken at 0.16 in., including mica, and the rising dotted line shows the maximum number of segments which can be used in a given size of machine without overstepping this limit. As the limiting voltage per segment, 20 has been adopted; this means that the 2,000-volt motor must have at least 400 segments; the 1,000-volt, 200 segments, and so on. The drooping dotted lines illustrate the minimum segments on this basis. Now it is obvious that all the practicable designs are embraced in the hatched space on the curves; all those outside this space will have either a narrower commutator bar than 0.16 in. or a greater average voltage per segment than 20. The most remarkable feature is the limiting effect of high rated speeds. It will be noted that the 2,000-volt motor is only practicable at a rated speed slightly higher than 350 r.p.m. However, it is also seen that 1,500 volts, which has been mentioned as the highest terminal pressure at which traction motors are running in regular service, is quite reasonable for a motor rated at the everyday speed of 550 r.p.m., though the 450-r.p.m. machine would be a better design even if a little heavier.

Mr. Peck. Mr. J. S. PECK (*in reply on behalf of the author*): I am afraid I shall have to leave the author to reply to most of the questions that have been asked, especially those by Mr. Lydall. With regard to standardizing voltages, it seems to be the general opinion of those who have spoken that we have not yet sufficient experience to fix these standards. This may be true, but would it not be advis-

able to adopt temporary standards? We have at present 600 volts, 1,200 volts, and 1,500 volts in regular commercial service, and 3,500 volts on a small experimental line. If the 1,200-volt system proves to be very satisfactory to the company that has installed it, will not that company insist on going ahead with 1,200 volts, although it may be the consensus of opinion among railway engineers that it is not the most desirable voltage, and in spite of the fact that other railways have adopted a different standard? Many standards have been adopted in a most haphazard manner, and it seems to me that it would be advisable to adopt certain temporary standards, say 1,200 and 2,400 volts, or whatever values are agreed upon as being most likely to meet our conditions here. As a result the railway companies will have at any rate something to guide them and towards which to aim. This is very much better than to have no standards whatever, with any railway free to choose any voltage. Mr. Firth asked whether regeneration was possible on motor coaches. I understand it is quite feasible. The question of overheating by regeneration, referred to by Mr. Roger Smith and others, is I think very fully appreciated. Most motors will stand some increase in temperature, because the modern motor is insulated with practically indestructible material, mica and asbestos, and in addition the heating current curve would be worked out with due regard to regeneration.

(Mr. STORER's reply to the discussion will be published in a later issue.)

#### NEWCASTLE LOCAL SECTION, 13 MARCH, 1916.

Mr. Beard. Mr. J. R. BEARD: The paper seems to me to be most timely. Owing to the war there is naturally an enforced period of inactivity in railway electrification and new schemes are being held in abeyance, so that it is just the time for a careful consideration of the direction in which new developments are likely to be made and also for a note of warning as to the danger of too individualistic policies with their aftermath of unstandard arrangements. The author states that the logic of his paper points to the necessity for early standardization, and this seems to be the keynote of the paper. While agreeing with him it seems to me to be more important to standardize quickly the position of overhead conductors and the higher voltages. I think no one questions that for main-line working 600 volts is too low, and the third-rail systems at this voltage, although they may grow considerably, will always remain local systems serving suburban traffic. Such traffic can, to a large extent, be considered by itself. Its rolling stock need not leave the particular district, and to a large extent it has its own tracks. Where tracks are used for both suburban and main-line traffic the method suggested in the last paragraph of the paper can be adopted, and I think it probable that apart from its greater convenience it would be no more costly in the long run than multivoltage control equipments, since I believe that on an ordinary single-voltage equipment the cost of the control apparatus represents some 40 to 50 per cent of the total. It is therefore a mistake to complicate the general question of railway electrification by paying any attention to the comparatively small 600-volt suburban systems at present in existence, particularly in view of the complications of running

higher voltage equipments over them. If we are not tied down to 600 volts there is no particular point in such voltages as 1,200 and 2,400 and the natural standards based on motor limits can be adopted. As the author points out, these are 1,500 and 3,000 volts, the former being adopted where a sound and tried system is required for immediate use with ordinary loads, and the latter being kept in reserve for specially heavy locomotive work and for future general use as apparatus is improved. In this connection it might be advantageous to standardize the use of 3,000-volt insulation on all overhead construction. One advantage of confining standardization for the moment to higher voltages and overhead conductors is that the new side-running third rail on the Lancashire and Yorkshire Railway has not yet been thoroughly tried, and it would be difficult to propose standards until its advantages and disadvantages over the more usual types have been definitely ascertained. It is a commonplace that the ease with which electrical measurements and calculations can be made enables alternative methods to be very accurately compared, but it is to be hoped this will not result in undue attention being paid to small percentage savings at the expense of standardization and through-running facilities. A standard must always be fixed to suit the average conditions, and is necessarily more or less inefficient for extreme conditions. Turning to the author's remarks on the trend of development, he appears to have established a strong case for field control. I am always surprised that this is usually effected by short-circuiting some of the field coils instead of by a series-parallel arrangement of the field winding. I should have thought the latter would have

allowed of a smaller and cheaper motor, as the whole of the field copper is always actively employed, whereas with the ordinary method about one-half of the field copper is idle as soon as the motor is up to full speed. I believe the series-parallel arrangement has been considered and I should be interested to know what are its disadvantages. It is most satisfactory to learn that the long-standing difficulties with regenerative control are in a fair way to being overcome, and I regret that the author has given so little information as to the methods adopted. Possibly in his reply to the discussion he will be able to supplement his remarks on this question. An interesting advantage of regenerative control, which I have not seen referred to, is that it makes the train speed at which the brakes are applied much less important and therefore gives designers a freer choice of motor characteristics, gear ratio, and acceleration. Those who have had experience of settling these items for specified conditions will appreciate what this means. As regenerative control necessitates shunt or separate excitation of the motor fields while the motors are acting as generators, I should think there is some possibility of flashing with variations in the line voltage, and I should like to know whether any such trouble has been experienced. A remark on page 534 appears to be somewhat at variance with other statements in the paper, and I should be glad if the author would explain it a little more fully. In describing the special double-armature motor he states that "the limit to the voltage will therefore be found elsewhere than in commutation"; whereas elsewhere in the paper he appears to consider that the voltage of an ordinary traction motor is limited by commutation difficulties.

Mr. T. CARTER: I am interested to find in the paper a reference to motors with unsaturated fields, as I come across similar problems in connection with lift motors. Sometimes physical impossibilities are specified, or results which are extremely difficult to obtain, even with added ampere-turns in the shape of series winding introduced for starting only; say  $2\frac{1}{2}$  times full-load torque with  $1\frac{1}{2}$  times full-load current, which means that a very weak field is necessary to start with, so that the series turns may very rapidly add flux; and this implies a relatively very large motor, which as a rule the customer objects to pay for, not appreciating the point so clearly brought out in the paper. It has been definitely established that a motor with an unsaturated field can be used in other connections actually to reduce the energy consumed in producing certain results, as when a reciprocating load with heavy peaks has to be driven. If a weak shunt excitation happens to be used, with a fairly strong series field, actually less energy consumption is registered on the meter than would be got by using the same total ampere-turns on a shunt winding only, as the series winding acting on the unsaturated field produces torque easily, gets the load over the peak quickly, and so brings about the result indicated. This sort of effect is also mentioned in the paper, and it is interesting to illustrate it in other connections. The regenerative-control experiments of the Johnson-Lundell Company in Newcastle have been referred to. One night the trial car was taken down one of the steepest hills in the city with the regenerative effect acting as a brake, but owing to the trolley coming off the overhead line the car ran away and

narrowly escaped becoming a complete wreck, insufficient precautions having been taken to guard against failure of the system. In railway work such a failure is less likely to occur owing to the multiple contacts with the feeding wire or rail, but the necessity of precautions is clearly indicated, in case some unexpected contingency should occur. The most important point in the paper seems to be that of standardization. I hope the Institution will take some strong measures to try to get voltages definitely settled, either through the proper Government Department or otherwise, so that the confusion already existing in ordinary continuous-current systems will not be repeated. It will certainly help manufacturers if some such arrangement is come to—and after all, although the paper mentions possible profit to manufacturers in a sort of aside, that is a point of some importance to the manufacturers themselves; and the ease of working which will be secured between railways will be well worth the small amount of preliminary trouble involved.

Mr. L. H. A. CARR: The author refers to saturated and unsaturated motors and gives characteristic curves in Fig. 1. It must be pointed out that the "unsaturated" motor is not really unsaturated, as can be seen by drawing a hyperbola on Fig. 1, which would give approximately the curve followed by a motor devoid of all saturation. It seems to be merely a question of degree of saturation. I would ask whether the author has any information concerning the success or otherwise of the Lancashire and Yorkshire Railway 3,500-volt system. With regard to standardization, it must not be forgotten that the position of the over-running outside third rail is already standardized in this country, dimensions having been agreed upon some 10 or 12 years ago by the railway companies. It is suggested that the fact that two railways, each using 600 volts, have recently equipped a system for a higher voltage, will probably assist standardization, rather than retard it, for the difficulties of carrying on two different systems will be the more realized, since they will be under the supervision of the same staff.

Mr. W. G. GUNS: Some experimental work was carried out several years ago in Newcastle on the Johnson-Lundell system of regenerative control applied to a tramcar. The difficulty of obtaining a machine suitable for both motoring and generating was got over by coupling up the field coils so that a coarse shunt winding was obtained during generation and a series effect during motoring. This involved a complication in the switchgear, but the windings on the machines were simple and all in use at once. A saving in power of about 30 per cent was effected by the use of regeneration on that system. I should like to ask how the author has overcome the difficulty of excessive voltage whilst generating, which may easily result in the lamps being burnt out.

Mr. C. TURNBULL: The double-armature motor appears to be a most interesting machine, but I do not see how room could be found for it on a truck of ordinary design. Some time ago I introduced a spring suspension for traction motors to the notice of a railway company, but it was found impracticable owing to absence of space. Traction motors are designed to the last inch, and the railway engineers were unable to try anything which required any more space than the standard motor. It

Mr. Carter.

Mr. Carr.

Mr. Guns.

Mr. Turnbull.

Mr.  
Turabull.

would be necessary to re-design the whole truck to get room for the double-armature motor illustrated in the paper. The re-introduction of regenerative control promises economy in railway working if the difficulties can be overcome. Some years ago Mr. Raworth tried it on tramways, but with unsatisfactory results. When generating, if the trolley came off the line, the motors developed excessive voltage, so destroying the car lamps; while on a small system, current was occasionally returned

to the busbars, so motoring the generators. This was overcome on Continental electric railways by putting a resistance across the busbars. Large systems, however, would be far less open than small ones to such defects, and there is no doubt that a good regenerative motor would do much to hasten the introduction of railway electrification on a large scale.

(Mr. STORER's reply to the discussion will be published in a later issue.)

### BIRMINGHAM LOCAL SECTION, 15 MARCH, 1916.

Dr. Garrard.

Dr. C. C. GARRARD: This paper appears to be largely a plea for standardization of railway equipment in this country, and the suggestion is made that this matter should be taken in hand by the Institution. I am afraid the author is of a somewhat sanguine temperament if he thinks that this will be done. As far as I am aware the Institution has not a Standardization Committee or any other machinery whereby this and other problems could be dealt with and decisions arrived at representing the considered view of the British electrical engineering profession. The American Institute of Electrical Engineers, for example, has such standing committees, and there is no doubt to my mind that the development of electrical engineering in this country is hindered by the failure of our Institution to take the lead in such matters. It is true that we have in this country the Engineering Standards Committee, upon which Committee our Institution has representatives and towards the support of which I believe our Institution contributes. The Engineering Standards Committee, however, deals with such a wide field covering the whole engineering industry, that electrical engineering can only receive a small share of its time and attention. It appears to me that these important electrical problems should be tackled by our Institution, who could put them into such a shape that they could be presented to the Engineering Standards Committee as the considered view of our profession. The Engineering Standards Committee could then see that our views fitted in with those of other branches of engineering and could eventually adopt them as a British Standard Specification. If this scheme could be arranged I am sure progress would be greatly accelerated.

Mr. Carter.

Mr. F. W. CARTER: I am pleased to see that the author emphasizes the necessity of using series motors for this work; there is in some quarters, even now, a disposition to argue in favour of shunt or separately excited motors, but from an operator's point of view the series motor is the only thing possible. The author in speaking of field control on page 522 says that this is "once more being employed where the service conditions justify its use." I should like to have from the author a more explicit statement of the service conditions which he considers to justify the use of field control, and if I give my own views on this point I trust that the author will not consider himself relieved from furnishing his. In laying out the design of a railway motor I invariably start with a simple equation which has a bearing on the question. If  $S$  is the maximum permissible speed of the train in miles per hour,  $D$  the diameter of the motor-driven wheels in inches,  $\pi$  the ratio

of gear reduction, and  $N$  the maximum speed of the motor armature in r.p.m., these quantities are connected by the equation

$$\frac{S \times 88 \times 12}{\pi D} = N.$$

Now the quantities  $S$  and  $D$  may be considered to be specified, whilst a maximum limit can be assigned to  $N$  by the designer. This is, of course, not the speed at which the armature would burst its binding bands, but a somewhat indefinite limit of satisfactory operation above which commutating troubles are to be anticipated in increasing degree, and particularly flashing-over troubles; the limiting speed is a little lower for an unsaturated motor than for a saturated motor, as the field is more liable to distortion, and the tendency to flash over correspondingly greater. The designer, therefore, in his own mind, gives a maximum desirable value to the quantity  $N$ . If, now, the motor is designed so as to use a larger gear reduction than that given by the above equation, the armature speed will sometimes pass beyond desirable limits; whilst if the gear reduction is less than that given by this equation, the motor is not used to the limit of its mechanical capacity and could be made more efficient, or lighter, or of greater capacity by reducing the number of armature bars, until the appropriate gear reduction satisfied the above equation. By starting the design with this equation, therefore, and deducing the number of armature bars in accordance with it, the most effective use is made of the active material. Now the above applies whether the motor is designed for operation with a single field or for field control. If a particular motor is taken with a particular gear, the operation with full field and with reduced field does not lead to characteristics such as are shown in Fig. 1, but to such as are shown in Fig. 3, in which with reduced field the speed is higher and the tractive effort lower throughout than with full field. For a particular service, however, the comparison between motors must be based on the assumption of approximately similar characteristics on the normal fields, such as are shown in Fig. 1. If it is desired to compare the operation of a particular motor with and without field control, then, in order to bring the two systems of curves approximately into coincidence as in Fig. 1, it is necessary to use a greater gear reduction for the field-control motor; but from the discussion given above it will be clear that in this case either the field-control motor runs to a higher speed than is desirable, or the saturated-field motor could be improved by re-designing it so as to satisfy the equation

given above; that is to say, the gear reduction is either too great in the field-control motor or too small in the other. The point to which I wish to lead, is that the comparison between field-control and saturated-field motors should be made not on the basis of using the same motor in the two cases, but on the basis of the best motor a designer could offer in the respective cases. Under these conditions the field-control motor would be somewhat heavier and more expensive than the saturated-field motor. To sum up the advantages and disadvantages of field control, I should say that the advantages are as follows:—

- (1) It results in a saving of energy as explained by the author.
- (2) For locomotive-hauled trains it gives an increase of flexibility, which is not only desirable but necessary in many cases.
- (3) For multiple-unit trains it frequently enables an otherwise unsuitable motor to be employed by using it nearer to the limit of its mechanical capacity.
- (4) It enables trains to meet special speed restrictions outside the ordinary schedules.

The disadvantages of field control when a comparison is made on the basis discussed above are:—

- (1) The motors are heavier and more expensive.
- (2) They are slightly worse in operation on account of the weakened field.
- (3) The control equipment is heavier and more complicated.

In many cases that I have examined, field control has not shown sufficient advantage over the ordinary series-parallel control to justify its use; at the same time it is frequently a valuable feature of which advantageous use can be made. In speaking of regenerative control the author mentions a system which is not yet in commercial service, but which is in course of development. The Chicago, Milwaukee, and St. Paul locomotive, as the author is doubtless aware, already makes use of a system of regenerative control which appears on the face of it to be somewhat similar to that indicated by the author;\* the field is separately excited by means of a generator which is, itself, excited by two opposing field windings, one, the main winding, which may be in shunt with the line and is adjustable by means of rheostats, and the other, a series winding, which carries the main current of the motor and which opposes the shunt field when the motor is regenerating. The effect of the series field is to oppose increase of current from the motors by reduction of voltage of the field-exciting generator. There is, of course, much more in the arrangement than this, and particularly in the controlling devices, but the above describes generally the self-regulating feature of the system. On page 527 the author speaks of the 600-volt third-rail system and says that this "is used interchangeably on the Metropolitan District, London and North-Western, and London

and South-Western Railways." I am not quite sure in Mr. Goster's what sense the author intends the word "interchangeably" to be taken, but, as is well known, the first two of these railways have an insulated return, while the third has an earthed return, and trains on one system cannot run on the other unless they carry a considerable amount of additional equipment to permit the interchange. I think it is improbable that there is any intention of interchange of traffic necessitating the running of trains between the London and South-Western and the other railways mentioned. The author brings out very clearly the complications introduced in running trains over lines employing different voltages, and furnishes a good argument for avoiding such a multiplicity of voltages; almost anything of this kind can be done by using suitable motors and a sufficiently complicated control arrangement, but I feel sure that the simpler arrangements appeal more strongly to the railway engineer. With regard to the author's conclusions, whilst I consider standardization to be highly desirable from some points of view, I can hardly blame the railway companies if they are indisposed to admit this at the present time; the advances in the direction of higher continuous-current voltage are too recent to justify us in concluding that we have reached finality, and in fact the system using 5,000 volts of which the author gives some description is only of last year's development. I am pleased to see that the author refers to the 600-volt system as being not only thoroughly established but as being "so well suited to the requirements of terminal electrification that it should be continued as one of the standards, at least for the present." This is the oldest system in use for operating railways, and there is always a disposition, when something newer appears, to consider that it is superior to the older and necessarily supersedes it; if, however, the question of electrifying such a system as the London Underground Railways came up at the present time, I believe the sound considerations given by the author, where he says, "the determining factor in the entire question will of course be the cost, not only of the original installation but the cost of operation and maintenance," would lead to the same solution as was arrived at by the Underground Railways Company at the inception of their project. In conclusion I regard the author's final paragraph as important. I believe that in this country the main lines and the local lines are very largely distinct, and if one system of operation were considered to be best for local service and another system for main-line service, the two systems would be largely concerned with separate tracks. If a different system of line conductors were considered to be desirable for the two classes of service, the few lines which it would be necessary to equip with both systems of line conductors would add little to the cost of the installation, as compared with the additional expense that would be incurred in adopting an unsuitable system of operation either for the main-line work or for the local work, in order that a single system of operation might be employed throughout the railway.

(Mr. STORER's reply to the discussion will be published in a later issue.)

\* See British Patent No. 26752 1913.

## MANCHESTER LOCAL SECTION, 21 MARCH, 1916.

Mr. B. Welbourn.

Mr. B. WELBOURN: I strongly endorse the plea which the author makes, that before it gets too late some attempt should be made to secure the standardization of voltage and collector systems in this country. It is very much to be hoped that in connection with railway-electrification work we shall not have a repetition of what has happened in the electric supply industry.

Mr. Barnes.

Mr. W. A. BARNES: The author points out in his concluding remarks the necessity for early standardization and, whilst asking strongly for something to be done, appears to be rather doubtful in the following sentences as to whether in many instances the appropriate time has yet arrived. It is unfortunate for standardization that continuous-current traction has progressed from low voltages to high and has not yet reached finality. Whilst high-voltage equipment will deal with low voltages, the reverse is not the case, and therefore before standardization can take place in the principal items connected with electric traction, some degree of finality as regards voltage must be reached. Voltage, I think, is the first thing to be standardized. A very important point which must be considered is that continuous-current traction is competing very strongly with alternating-current traction in the only advantage the latter presents, namely, high-voltage transmission, and on this account it would not be policy at the present time to standardize, say, 1,200 or even 2,400 volts. The author states on page 534 that 1,500 volts is about the maximum voltage which can be used with a 4-pole railway motor; against that we have on the Holcombe Brook section of the Lancashire and Yorkshire Railway motors operating successfully with 1,800 volts across their terminals. Another point against standardization at the present time is that such a course, in a great measure, stops progress. One has only to turn to the standardization of the 4 ft. 8½ in. gauge for railway tracks to see how seriously it has hampered the progress of the steam locomotive. The question, however, has not been lost sight of entirely in this country, and the locating of the third rail, which the author asks for on page 533, was brought before a meeting of railway engineers held in the Railway Clearing House, London, so long ago as March 1903. It was then decided that the most advantageous position for the third rail was that the contact surface should be 3 in. above the track rail, and that the horizontal distance between the centre of the track and the centre of the third rail should be 3 ft. 11 in. This was for an over-running shoe. This standard was made at a time when it was thought that 600 volts would not be exceeded for continuous-current traction, and it has been adopted by the railway companies who have electrified their lines since then. In fact the Liverpool Overhead Railway changed over their system from a central third rail to the standard, which permitted the inter-running of trains with the Liverpool and Southport section of the Lancashire and Yorkshire Railway. During the past few years, however, the continuous-current traction motor has been greatly improved; so much so, that the 1,200-volt motor is perhaps more reliable than the 600-volt motor was 10 years ago. The 600-volt third rail, however, is not sufficiently safe and well protected to be used on 1,200 volts, and the problem has been to decide whether to keep to the 600-volt system with

its attendant transmission losses, or to depart from the Mr. standard in order that the rail should be thoroughly protected to prevent the staff coming in actual contact with it. I leave out the question of overhead construction owing to the latter's many disadvantages. On the Manchester-Bury section of the Lancashire and Yorkshire Railway where 1,200 volts is in operation this has led to the adoption of the side-contact rail, which is adequately protected throughout its whole length, and thus progress has nullified the earlier standard set up. This side-contact rail is, however, mounted in the same relative position as the standard, and, apart from the question of protection, could be used with an over-running shoe. In the section dealing with control, the author shows diagrams of arrangements of gear to operate on various voltages. With the arrangements shown in Figs. 7 and 8, 56 and 36 switches respectively are required, the majority of which will have to be designed for the maximum voltage, viz. 2,400. It is undesirable to carry these under the car, and room will therefore have to be found for them on the car floor; and when they are accommodated, together with the equipment for regenerative control and the apparatus mentioned on page 527 for changing the position of the shoe, a considerable inroad will have been made on the floor space, and the car will not only have its earning capacity as a passenger-carrying vehicle seriously diminished, but will cost much more for maintenance and running charges. It is probable that in trunk-line electrification any one railway company would limit itself to one system and it would only be inter-running trains which would be affected. I would suggest that such trains should be of ordinary stock worked by electric locomotives, which would be changed at the junction of the two systems; and that where through coaches only were involved they should be trailer coaches used in conjunction with motor coaches in the ordinary way. The author points out on page 522 that the unsaturated motor will operate more efficiently than the saturated motor on a frequent stopping service. While this is true, an examination of Fig. 1 shows that the tractive effort for a given current, and therefore the acceleration, are less, a state of affairs which is not desirable for the service in question. If the same acceleration is required with the unsaturated motor, the latter must be larger, a very difficult matter to arrange for in cars of high power, owing to the limited space available. The choice of motor thus depends on the relative importance of the efficiency of working and the efficiency of service.

Mr. T. FERGUSON: The author's description of new features in connection with modern equipments makes us realize that progress is taking place in the art of electrification. The very fact, however, that we are progressing has led us into difficulties on the voltage question. I thoroughly endorse the author's view that some steps should be taken towards standardization, and I quite agree with the last speaker that the first step is to try and standardize line voltage. The interrunning of trains over systems employing different voltages has been amply dealt with in the paper, and in the numerous diagrams the author shows us clearly what complications we may expect and the relatively large number of switches

that would be necessary. In maintaining equipments of this kind, however, it is well to remember that, so far as the main control is concerned, we simply have to deal with a number of similar contactors or reverser-type switches, all of these being fairly well-known pieces of apparatus which the maintenance staff is quite accustomed to, hence the maintenance is increased only by multiplying the number of similar pieces of apparatus. The case of the auxiliaries required for high voltages and different voltages is very different and is in my opinion by far the hardest part of the problem. As a rule it means the introduction of a new type of apparatus, more or less unexploited and undeveloped. The author, however, has shown us rather an easy way out of the difficulty by using storage batteries connected to the negative side of the circuit, whereby he is enabled to employ standard compressor motors and blower motors, as well as standard control voltages, thus getting rid of the difficulties which ensue when dynamotors or double-commutator motors or similar devices have to be employed. I think this is a very valuable idea and helps very much to simplify the problem of auxiliary control.

In connection with the first part of the paper, I think the author defines very clearly the starting-off point for comparison or consideration of speed control by field variation when he says in speaking of the shunt motor that: "Moreover, no greater speed variation is possible with it than the series motor, because this depends on the armature and the allowable ratio between the field and armature ampere-turns necessary to secure stability." The field-controlled motor and also the non-saturated field motor are used primarily as a means for reducing the energy consumption in the rheostats. The author goes to some considerable detail in Fig. 2 to illustrate how these rheostatic losses increase as the speed at which the motor curve is reached rises. The curve shown of course follows the law of squares. The reduction of energy loss in the rheostats can be accomplished in two ways, either by accelerating on the rheostat with a strong-field motor and weakening the field immediately the strong-field motor curve is reached, or by designing a motor without field control but with a non-saturated field. In the former case, if the limit defined by the author did not exist, the obvious thing to do would be to make a low-speed motor with a ratio of full field to armature ampere-turns of something like 1:1 or 1:2, and then weaken the field considerably so as to obtain the desired schedule speed. By doing this, however, the aforesaid ratio immediately becomes too small and the motor is very sensitive and liable to flash over. Under the circumstances, therefore, we have to begin by making up our mind as to what is the lowest ratio at which we could safely operate in the weak-field condition, and then work backwards by strengthening the field as much as we can for the full-field curve. Unfortunately, we usually find in strengthening the field that saturation is reached very early, and we therefore cannot get so great a drop in speed and saving in energy loss as we desire. This is clearly seen by an examination of Figs. 1 and 2. In the case of a non-saturated field motor trouble is seldom experienced with regard to a minimum ratio of field to armature ampere-turns, as the air-gap is usually fairly long and absorbs a considerable number of ampere-turns. In a motor of this

type the best economy is obtained when the accelerating current is made as high as possible, as the speed at which the motor curve is reached comes down comparatively quickly as the accelerating current is increased. We have therefore two effects: the first, by increasing the acceleration and therefore decreasing the time on the rheostat; the second, by reaching the motor curve at a lower speed. In the case of equipments which have to run at comparatively high speed on the suburban sections of a railway, say with distances between stops of from 2 to 4 miles, and also have to run on the city lines with distances between stops of perhaps only half a mile, I think field control is the proper thing; but in deciding a question of this sort for any particular case it should be borne in mind that field control requires extra switches and also extra cables, involving additional capital cost and additional maintenance, and there are cases in which it will be found that it would pay to put the money and material into building a larger motor having a non-saturated field. The author clearly points out that we cannot have a field-controlled motor or a non-saturated field motor at the same cost as a standard motor, and I thoroughly agree with him when he says, on page 522, that "if this point were thoroughly borne in mind, the manufacturer of the unsaturated motor would not be penalized on account of small rating, or on account of greater weight with equal ratings, and the railway company would operate with greater efficiency."

Dr. W. CRAMP: The paper naturally divides itself into two parts. The first part refers to the suitability of the series motor for railway electrification, especially as regards torque characteristics; but there are several points which need explanation. For instance, emphasis is laid upon what are called saturated and non-saturated fields, but no indication is given as to the point at which the distinction between saturated and unsaturated is drawn. I find it impossible, therefore, to analyse the curves given in Fig. 1. Later the author refers to the "sluggishness" of shunt fields. Does he mean that the field does not respond so quickly to current changes because of the greater self-induction due to the large number of field turns, or is some other meaning to be attached to this expression? But by far the most important point in this section of the paper is the plea which the author makes for a revised specification for railway motors. He points out that the 1-hour rating does not produce that motor which is best suited for railway electrification; and whether his plea for the unsaturated as against the saturated motor be justified or not, one thing is certain, viz. that he has made out a case against the rating of railway motors on the 1-hour basis. It is to be hoped that the Institution or the Engineering Standards Committee will go into this question with the object of sanctioning a more rational basis for specification. Such a basis has been already both called for and suggested by Dr. Pohl in two papers<sup>2</sup> read before this Institution, to which I would direct attention. The author next deals with the question of regenerative control, illustrating his remarks by means of Figs. 4 and 5. Of these the former is merely  $V^2/2g$  plotted against  $V$ ,  $V$  being the initial velocity of the train in miles per hour. The object of publishing so elementary a relationship is not at all obvious, especially when Fig. 5 is considered. In the latter, the ordinates of Curve 1 should, in the

Mr. Ferguson

Dr. Cramp

<sup>2</sup> *Journal I.E.E.*, vol. 45, p. 219, 1910; *Ibid.*, vol. 48, p. 178, 1911.

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absence of any information to the contrary, be 0.84 times the ordinates of Fig. 4, since  $0.84 \text{ watt-hour} = 1 \text{ foot-ton}$  nearly. However, a few readings of Figs. 4 and 5 show that this relationship does not apply, and the only explanation seems to be that Fig. 5 includes some allowance for the energy of rotating parts not specifically mentioned by the author. Clearly the exact basis of this curve should be stated. Curve 2 in Fig. 5 is Curve 1 minus a constant amount of energy, in which presumably again an allowance has been made for rotating parts, and this explanation must be held to account for the figure of 19 watt-hours per ton which is said to correspond with 25 miles per hour. Without some such addition the figure should be 17.6 watt-hours per ton. Curve 3 in Fig. 5 is apparently obtained by deducting from Curve 2 the amount of energy absorbed by train resistance in changing its speed from V to 10 miles per hour. To get this we need to know: (1) what figure is assumed for train resistance, and (2) what retardation is assumed. It is to be hoped that in his reply the author will give answers to these questions, as well as indicate the limits which practice has assigned to retardation in various cases. It is worth while noting that if the train-resistance coefficient and the retardation are constant, then the ordinates of Curve 3 should bear a constant relationship to the ordinates of Curve 2, which ratio in typical cases might well be given by the author. The second part of the paper is the most eloquent plea for standardization that can possibly be put forward, because it shows into what confusion railway equipment will be thrown if some control is not quickly exercised. It should be remarked, incidentally, that the adoption of the single-phase system would obviate many of the difficulties which the author considers. In fact the paper might be turned into a demand for the single-phase system so long as there is no co-ordination between the railway companies as regards voltage. In a single-phase system there is only one thing that need be standardized, and that only within certain limits, namely the frequency. This should not be a difficult thing to decide upon. Series-parallel operation of transformer or motor windings would meet all other variations. It is ridiculous to construct trains on such short lengths of line as we have in this country with so much complicated apparatus to change from one railway company's system to another. If there must be voltages varying over the range suggested by the paper, the continuous-current system should not be adopted at all. In England, having regard to the fact that the lengths of line are very short, and therefore not comparable with the lines in America, the only solution is some sort of national control of railways. I will not say nationalization, but some form of control which will prevent a company from adopting a system different from that adopted by another company without showing good cause for the difference and the method to be adopted to ensure interchangeability. That seems to be a summary of the latter half of the paper, and I think the importance of the subject should be made clear before it is too late. Any delay in now taking action will lead to vast expenditure later on. For ultimately standardization of equipment will have to take place, and companies not in line with the standard will be forced to get new equipment, for which the public will have to pay. In conclusion I would ask the author to render Figs. 7-11 more intelligible by

giving a list of the symbols used with their meanings. Dr. C.  
[This has since been done.]

Professor E. W. MARCHANT: With regard to the difference between saturated and unsaturated motors, it would be very interesting if we could get some idea as to what are the limits of flux density in the two motors. It is only a matter of degree of saturation for the two types. The saturated motor is obviously a cheaper motor than the unsaturated motor. The author puts forward the series-parallel controller as having been developed mainly on the ground that it enabled speed regulation to be easily effected, but I think there is another important point. One of the main advantages of series-parallel control lies in the greater efficiency in starting. The maximum possible efficiency in starting with series-parallel control and two motors is 67 per cent—that is, in starting up we must waste in the rheostats 33 per cent of the energy supplied—whereas with ordinary rheostatic control the smaller loss is 50 per cent. I should like to ask what is the maximum current that can be collected by a trolley. If we take the ordinary limit accepted in this country of from 150 to 200 amperes, it is clear that we must use a very high voltage on the trolley wire if we are to get anything like the amount of power wanted for driving a railway. I should like to say a word or two on the question of the limits of voltage for a continuous-current dynamo or motor. Some four or five years ago, when Mr. Catterston-Smith was in my laboratory he made a number of experiments as to the possible limit of voltage on a continuous-current motor. A motor was designed which would work under compressed air at a pressure of 200 lb. per sq. in. The armature was designed for 3,000 volts and he succeeded in getting a small output of about 3 kw. from the machine, which had two poles, the commutator diameter being only 4 in. The designing of the bearing was the most difficult problem, because there was a pressure on one side of the bearing of 200 lb. per sq. in. and no pressure on the other. The bearings had to be very tightly packed and it was only after a great deal of time and trouble that they were made at all satisfactory. The experimental motor was designed with the idea that such a machine might be used in connection with high-voltage continuous-current traction. The mechanical difficulties that arose seemed to be too serious to warrant much hope of final success. With regard to standardization, I would remind members of this Local Section that we had an interesting discussion on this subject at one of our annual dinners some time ago. It was then put forward by Alderman Walker to be very desirable that electric railway equipment should be standardized, but a representative of the manufacturers replied that he thought it would be a very serious mistake because "if we once standardize we shall stop all progress." We seem now to have changed that position, for the author recommends the standardization of motors, which, I think, is a great step forward.

Mr. A. P. M. FLEMING: I should be glad to have further information on some minor points. On the last page of the paper the author says, "the question of insulating motor and control for such high voltages would also appear to be less serious than might have been expected." One would like to know what is meant by "less trouble than might have been expected." Personally I should expect a great deal of insulation trouble with these high

Mr. Fleming

voltages, particularly in view of the extremely exacting conditions of railway services in regard to moisture, dust, and oil. In this connection I should be glad to know whether the maintenance costs are likely to be much increased for voltages of 3,000 or 5,000. It would also be interesting, though it is outside the scope of the paper, to hear whether the mercury-vapour control mentioned is really successful, what the limits of its use are, and at about what voltage it becomes economically desirable to use such an apparatus.

Mr. C. H. WORDINGHAM: I am very interested in standardization, but it must be recognized that directly we standardize anything we limit progress to a certain extent. It depends a great deal of course on how we standardize. For general standards, such as the Engineering Standards Committee deal with, it is essential that we should confine standardization chiefly to questions of interchangeability and not attempt to standardize design. In connection with railway work a great deal can be done in the way of standardization, and in the particular work in which I am interested it does pay to standardize details which can be common to various items of plant without restricting design too much, but if we go in for a rigid standardization, mechanical and electrical, then the danger of stifling progress is very serious.

Mr. J. S. PECK (*in reply on behalf of the author*): Any remarks I make in reply to the discussion should be taken as expressing merely my own opinions; the author's reply will be published later in the *Journal*. Mr. Barnes does not think it advisable at present to standardize voltages. I agree that it is not possible to standardize completely at present, for by doing so we might seriously hamper progress; but if we were to adopt certain provisional standards, say 600, 1,200, and 2,400 volts, or whatever pressures were considered to be desirable, it would prevent one railway company adopting, say, 1,200 volts and a neighbouring company some other voltage which might at the moment seem to possess some special advantage. Unless some effort is made to standardize we shall very soon have the same multiplicity of voltages that exists in the United States, where pressures of 500, 600, 750, 1,200, 1,500, 2,400, 3,000, and 5,000 volts are in use. In this country we have already 600 volts, which is more or less the standard for the lower pressures, 1,200 volts on the Lancashire and Yorkshire Railway, and 1,500 volts on the North-Eastern Railway. Mr. Barnes says it is not a very serious difficulty, because if two railways use different voltages they need not interchange electric motor coaches but can get over the difficulty to a certain extent by using electric locomotives, each company operating its locomotives over its own system only. To me this seems a very incomplete solution of the problem. If the railways are ever amalgamated one of the first things to be done will be to adopt a standard voltage, which will necessitate "scrapping" a large amount of expensive equipment. Why should not a standard voltage be adopted, as would be the case if all the railways of the country were under one management? Mr. Barnes also referred to the multiplicity of switches in Fig. 7; I think the author used that as an example of what we might require if we continued to increase the number of voltages. Dr. Cramp asked why the shunt motor is more sensitive to fluctuations in line voltage. The self-induction of the field of the shunt

motor, owing to the large number of turns of fine wire, is of course very much higher than that of the series motor with a few turns of large wire. If the pressure is removed from the line and then suddenly switched on again, or whenever there are large fluctuations in the line voltage, there is a tendency for very large rushes of current to occur. The field of the shunt motor is sluggish in building up, and the very heavy armature current distorts the field and is apt to produce flashing. Dr. Cramp complains that Fig. 4 is too elementary and should not have been published. It seems to me to be a very useful figure, as it indicates in such a perfectly clear manner what it was intended to show, namely, the height to which the track at the station must be elevated in order to bring the train to rest without braking, when running at different speeds. With regard to Fig. 5, the first curve shows the total energy stored, and a certain amount of rotational energy is taken account of. Curve 2 is the total available stored energy, after deducting the amount remaining at a speed of 10 m.p.h. Curve 3 shows the stored energy less the loss due to resistance as the train slows down. The lowest curve is simply the amount of energy which can be returned to the line assuming 80 per cent efficiency in the motors. Professor Marchant wants to know the maximum current which can be collected from a trolley wire. The figure varies a good deal and is dependent on the type of trolley and on the size of the wire, but 250 to 300 amperes I should say could be collected without much difficulty, even at high speeds. I saw an advertisement a short time ago of a double pantograph trolley which could collect 4,000 amperes when running at 40 m.p.h. The experiment which Professor Marchant describes, of running a small 3,000-volt commutator under compressed air, is very interesting; I do not know of any test of a similar nature having been made elsewhere. It is well known that compressed air is an excellent insulator, and its use has been suggested in connection with transformers in order to stop static discharges. Mr. Fleming referred to the author's statement on the last page as to the trouble with control equipment. I think the author means that they expected a certain amount of trouble with the 5,000-volt control equipment and they had not experienced any. In a letter to me he states that the only difficulties experienced so far have been due to earths on the resistances when running through slush and snow. That, however, was very easily remedied. As to maintenance costs, no figures are available at present, I think, even for the 2,400-volt or 3,000-volt equipments; it is difficult to get such information when a new road is first put into service. Experiments have been carried on for many years with the mercury-vapour converter, and the apparatus appears to be almost in commercial shape. I understand that a number of these converters are running in parallel with 600-volt rotary converters for supplying railway lines, but it is very difficult to get any definite information. Mr. Fleming also asked at what voltage it was customary to adopt the insulated return. As far as I know, an insulated return is only used where there is fear of electrolysis on water mains, gas pipes, or other steel structures, and of course the higher the current the greater is the danger from electrolysis.

(Mr. STORER's reply to the discussion will be published in a later issue.)

## REPORT OF THE COUNCIL FOR PRESENTATION AT THE ANNUAL GENERAL MEETING OF 11 MAY, 1916.

At this, the Forty-fourth Annual General Meeting of The Institution of Electrical Engineers, the Council present to the members their Report for the year 1915-16.

### MEMBERSHIP OF THE INSTITUTION.

The changes in the membership since the 1st April, 1915, are shown in the following table:—

	Inst. Mem.	Mem.	Assoc. Mem.	Assoc.	Grad.	Stud.	Total
Totals at 1 April, 1915	8	1,526	3,501	566	354	802	6,817
<b>Additions during the year:—</b>							
Elected	1	8	10	6	35	140	200
Reinstated	..	1	2	..	1	2	6
Transferred to	..	20	70	1	28	..	119
Total	1	29	88	7	64	142	331
<b>Deductions during the year:—</b>							
Deceased	2	28	24	9	2	14	79
Resigned	..	18	34	23	8	13	96
Lapsed	..	..	..	..	..	..	..
(Estimated) ..	8	49	18	8	98	178	..
Transferred from	..	1	10	3	18	78	110
Total	2	55	123	53	39	203	472
Net Decrease	..	..	..	..	..	..	141
Totals at 1 April, 1916:—	7	1,500	3,400	520	382	801	6,676

In addition, 49 candidates for Associate Membership have been approved by the Council during the year for admission to that class on condition that they pass the Institution examination or otherwise satisfy the examination regulations. Of these, 12 are Graduates, 10 Students, and 27 non-members.

### HONORARY MEMBER.

The Council have pleasure in recording the announcement made at the Ordinary Meeting of the 18th November last, that they had elected M. Maurice Leblanc, of Paris, to be an Honorary Member of the Institution.

### HONOURS CONFERRED.

His Majesty the King has conferred the honour of a Baronetcy upon Sir Henry Norman, M.P. (Associate), the order of Knight Commander of the Bath upon Lord Moulton, F.R.S. (Member), and Colonel Sir H. C. L. Holden, F.R.S. (Member), and Knighthoods upon Sir William Slingsby (Member), and Sir George Franklin (Associate).

Military distinctions arising out of the war have been awarded as follows:—

### Companion of the Bath.

Chambers, Lieut.	West Riding Divisional	Member
Col. J. C.	A.S.C.	

### Distinguished Service Order.

Chapple, Major F. J.	North Midland R.G.A.	Associate Member
Cowan, Major S. H.	Royal Engineers	Associate Member
Davidson, Captain	Royal Engineers	Associate Member
A. E.		Member
Leaf, Captain H.M.	Royal Marine Light Infantry	Member

### Victoria Cross.

Robinson, Lieut.	Royal Navy	Associate Member
Com. E. G.		

### Military Cross.

Goulden, 2nd Lieut.	Royal Garrison Artillery	Associate Member
C. H.		
Groom, Lieutenant	Royal Warwickshire Regt.	Graduate
H. R. L.		
Gwyther, Lieutenant	Manchester Regt.	Student
H. J.		
Lefroy, Captain H.	Royal Engineers	Associate Member
P. T.		
Massie, Lieutenant	Royal Engineers	Associate Member
I. W.		
Podmore, Lieutenant A.	Royal Engineers	Associate Member
Sherwell, 2nd Lieut.	Royal Field Artillery	Student
O. W.		
Sparks, Lieutenant	Royal Engineers	Associate Member
A. C.		
Tabor, Lieutenant	Royal Field Artillery	Student
A. R.		

### Distinguished Service Cross.

Boissier, Lieutenant	Royal Naval Division	Associate Member
E. G.		

### Distinguished Conduct Medal.

Doig, Private A. M.	Manchester Regt.	Associate Member
Saunders, Corporal	New Zealand Engineers	Graduate
C. W.		
Wood, Private P. J.	London Regt.	Student

### Distinguished Service Medal.

Murray, Sapper	Divisional Engineers, R.N.D.	Associate Member
J. H.		

### Mentioned in Despatches.

Angwin, Major	Lowland Signal Service R.E.	Associate Member
A. S.		
Bicknell, Lieutenant	Royal Garrison Artillery	Student
C. R.		
Carey-Thomas, Captain H.	London Army Troops, R.E.	Associate Member
Casson, Captain W.	London Regt.	Member

Cottrell, Commander W. H.	R.N.V.R.	Associate	Slater, Private E. C.	Manchester Regt.	Student
Damaut, Sapper E. L.	Divisional Engineers, R.N.D.	Student	H.		
Downes, Lieutenant H. L.	Liverpool Regt.	Associate	Thornton, Lieutenant J. M.	Royal Engineers	Student
Edmonds, Lieutenant C. H. W.	Royal Engineers	Associate	Tidd, Captain E. G.	Highland Light Infantry	Member
Evans, Major L.	Royal Engineers	Member	Young, 2nd Lieut. A. Y.	Royal Scots Fusiliers	Student
Hann, Petty Officer C. S.	Hawke Batt., R.N.D.	Associate	<b>Died of Wounds.</b>		
Hart, Lieutenant L. V.	Royal Engineers	Student	Bradbury, Sergeant G. S.	Manchester Regt.	Associate
Iles, Major F. A.	Royal Engineers	Associate	Doig, Private A. M.	Manchester Regt.	Associate
Knox, Major G. S.	Royal Engineers	Member	Eardley-Wilmot, 2nd Lieut. G. H.	Machine Gun Corps.	Graduate
Lefroy, Captain H. P. T.	Royal Engineers	Associate	Gilbert, Private J.	Manchester Regt.	Associate
Morcom, Lieutenant R. K.	Divisional Engineers, R.N.D.	Member	Hill, Private C. H.	Canadian Infantry	Student
Oliver, Captain T. W.	Royal Engineers	Member	Hulton, Corporal R. P.	Divisional Engineers, R.N.D.	Associate
Smith, Captain T. V.	Royal Flying Corps	Associate	Ogden, Sapper A. H.	Divisional Engineers, R.N.D.	Student
Spittle, Major G. H.	Divisional Engineers, R.N.D.	Associate	Read, Lance-Corpl. A. H.	Divisional Engineers, R.N.D.	Associate
Stace, Captain R. E.	Royal Engineers	Associate	Swinton, 2nd Lieut. E.	Royal Field Artillery	Student
Stuart, Brig-General A. M., C.B.	Director of Works	Member	Tilley, Sapper F. E.	Divisional Engineers, R.N.D.	Associate
Tuppen, Lieutenant H. R.	Army Service Corps	Student	Warburton, Sapper P. A. E.	New Zealand Engineers	Graduate
Williams, 2nd Lieut. R. A.	Royal Engineers	Associate	Winkworth, 2nd Lieut. W.	Northumberland Fusiliers	Associate
		Member			Member
			<b>Died.</b>		
			Duesbury, Private T.	Royal Berkshire Regt.	Associate
			Foote, Trumpeter N. V.	Australian Light Horse	Student
			Seligmann-Lui, Colonel G. P.	French Military Telegraphs	Member
			Woodside, Sapper H.	Divisional Engineers, R.N.D.	Student

## ROLL OF HONOUR.

Thirty-four members have been reported during the year to have lost their lives in the service of their country, and their names, together with their military ranks and the names of their Corps, are set out in the following list:—

## Killed in Action.

Alderson, Lieutenant A. R.	Royal Engineers	Associate
Brydon, Lieutenant A. W.	Queen's Royal West Surrey Regt.	Member
Byng, 2nd Lieut. H. G.	Border Regt.	Student
Casson, Captain W.	London Regt.	Member
Davison, 2nd Lieut. H. J. G.	Lancashire Fusiliers	Associate
Forbes, 2nd Lieut. J.	Royal Engineers	Student
Gardiner, Major A.	Royal Engineers	Associate
Gudgeon, 2nd Lieut. S.	Manchester Regt.	Student
Henry, Sub-Lieut. W. J.	Anson Batt., R.N.D.	Associate
Hoyle, Sergeant E.	Honourable Artillery Company	Member
Hunt, Trooper F. E.	Sussex Yeomanry	Student
Lloyd, Private N. V.	Manchester Regt.	Associate
Miller, Lance-Corpl. C. W.	Manchester Regt.	Student
Newman, Captain V. W.	Loyal North Lancs Regt.	Associate
		Member

## OTHER MEMBERS DECEASED.

It is with deep regret that the Council have to record the deaths of Mr. C. E. Spagnoletti, Past-President, Professor Eric Gerard, Honorary Member, and Mr. Robert Hammond, Honorary Treasurer.

Mr. C. E. Spagnoletti, who was elected an Honorary Member in 1912, and whose connection with the Institution dated from his admission to membership in 1872, had filled the office of President in 1885, after having previously served as Ordinary Member of Council and Vice-President from 1874 to 1885.

Professor Gerard, the distinguished Head of the Institut Electrotechnique Montefiore at Liège, was elected a Foreign Member of the Institution in 1883, and an Honorary Member in 1914.

Mr. Robert Hammond had held the office of Honorary Treasurer of the Institution since 1902, and had previously been a Member of Council from 1899 to 1902.

The Council have also to deplore the loss of well-known members in Lord Alverstone, formerly Lord Chief Justice of England, Mr. Ernest Danvers (Local Honorary Secretary and Treasurer for Argentina, 1900-1915), Mr. Augustus Eden (Member of Council, 1890), Mr. F. Higgins (Member of Council, 1877-8), Mr. H. Kingsford (Local

Honorary Secretary and Treasurer for Peru, 1886-1916), Mr. F. G. Maclean (Chairman of Calcutta Local Centre, 1901-2), Mr. H. A. Mavor (Chairman of Glasgow Local Section, 1902-1903), Sir Arthur Rücker (Member of Council, 1887-8), Mr. Herbert Taylor (Member of Council, 1897-1900), Captain E. G. Tidd (Chairman of Glasgow Local Section, 1909-1910), and Colonel Sir Charles M. Watson, K.C.M.G., C.B. (Member of Council, 1874).

In addition to those who have died on active service, the following members have died during the year :—

#### *Honorary Members.*

Gerard, Professor Eric. | Spagnoletti, Charles Ernest.

#### *Members.*

Alverstone, The Rt. Hon.	Lacey, Frederick William.
Viscount, G.C.M.G.	Larkin, Thomas J.
Chisholm, John William.	Lloyd, Robert Samuel.
Crookes, Henry.	Maclean, Frederick Gurr,
Danvers, Ernest.	C.I.E.
Dawbarn, Robert Arthur.	Mavor, Henry Alexander.
Donovan, Henry Cornelius.	Neale, George Alfred.
Eden, Augustus.	Parker, Thomas.
Hammond, Robert.	Rücker, Sir Arthur William,
Higgins, Frederick.	F.R.S.
Huber, Colonel Peter Emil.	Smith, Professor Robert
Kennedy, John Nassau C.,	Henry.
Major, R.E.	Taylor, Herbert.
Kingsford, Herbert.	Varley, Frederick Henry.
White, Herbert Brandon.	

#### *Associate Members.*

Bevenue-Miller, Edwin D.	Munro, Andrew Hunter.
Bonnett, Charles.	Smith-Saville, Robert W.
Horley, George.	Thomas, Ernest Byers.
Lee, George Phillip.	Wayne, Philip G.
Zapata, Felipe.	

#### *Associates.*

Beech, Ernest W.	Seager, James A..
Cassells, Walter R.	Slater, William P.
Cooke, Walter E.	Watson, Colonel Sir Charles
Palmer, Wallace Leonard.	M., K.C.M.G., C.B.

#### *Graduate.*

Sadick, Mehmed.

#### *Student.*

Rock, Henry Willoughby D.

#### MEETINGS AND PAPERS.

During the past twelve months 12 Ordinary Meetings and 19 Council Meetings have been held. The usual Standing Committees have met regularly, and there have also been meetings of other Committees appointed by the Council for the consideration of special matters, the total number of Committee Meetings held during the year being 86.

There have been 39 meetings of Local Sections, viz. Birmingham Local Section 7, Manchester Local Section 11, Newcastle Local Section 5, Scottish Local Section 6, Western Local Section 4, and Yorkshire Local Section 7. Meetings have also been held of the Local Centres at Calcutta, Cape Town, and Hong-Kong.

The following is a list of papers read during the Session 1915-16, in addition to which 15 papers not read at meetings have been accepted for publication in the *Journal* :—

<i>Author.</i>	<i>Title.</i>
C. P. SPARKS, Member.	Inaugural Address as President.
W. L. CARTER, Member.	Address as Chairman of Hong-Kong Local Centre.
P. V. HUNTER, Member.	Address as Chairman of Newcastle Local Section.
Lieut.-Col. J. F. LISTER, Member.	Address as Chairman of Birmingham Local Section.
D. E. ROBERTS, Member.	Address as Chairman of Western Local Section.
D. A. STARK, Member.	Address as Chairman of Scottish Local Section.
B. WELBOURN, Member.	"The production and properties of electrolytic copper" (Address as Chairman of Manchester Local Section).
H. H. WRIGHT, Member.	Address as Chairman of Yorkshire Local Section.
J. R. BEARD, Associate Member.	"The design of high-pressure distribution systems."
G. DEARLE, Associate Member.	"The economical production of power from coke-oven gas."
Professor A. B. FIELD, Member.	"Some difficulties of design of high-speed generators."
H. H. HARRISON, Associate Member.	"The principles of modern printing telegraphy."
C. S. JEFFREY, Associate Member.	"Some notes on the cooling of condensing water."
H. JOSEPH, Associate Member.	"Hire and maintenance of continuous-current motors."
V. A. MAKINNEY and E. STROUD.	"Good lighting and its immediate effects from the economic standpoint."
D. M. MACLEOD, Member.	"Branches from extra-high-tension circuits."
J. D. MORGAN, Associate Member.	"Notes on the ignition of explosive gas mixtures by electric sparks."
E. V. PANNELL, Associate Member.	"Continuous-current railway motors."
O. L. RECORD, Associate Member.	"The testing of underground cables with continuous current."
Professor C. A. M. SMITH, Associate Member.	"Electric generating stations in China."
N. W. STORER.	"The use of continuous current for terminal and trunk-line electrification."
Professor MILES WALKER, Member.	"The predetermination of the performance of dynamo-electric machinery."
G. WILKINSON, Member.	"Electric heating: its present position and future development."
E. T. WILLIAMS, Member.	"The electricity supply of Great Britain."

#### ANNUAL DINNER AND ANNUAL CONVERSAZIONE.

On account of the war the Council have decided that the Annual Dinner and the Annual Conversazione should not be held this year.

#### KELVIN LECTURE.

The seventh Kelvin Lecture was delivered by Dr. Charles Chree, F.R.S., on the 17th February last, the

subject of the lecture being: "Lord Kelvin and Terrestrial Magnetism."

#### PREMIUMS.

The following premiums for papers have been awarded by the Council. In accordance with precedent, in deciding upon these awards the Council have not taken into account papers contributed wholly or in part by Members of Council.

*The Institute Premium (value £25).*  
J. R. BEARD. "The design of high-pressure distribution systems."

*The Faber Premium (value £15).*  
H. H. HARRISON. "The principles of modern printing telegraphy."

*The John H. Johnson Premium (value £10).*  
Professor A. B. FIELD. "Some difficulties of design of high-speed generators."

*The Davis Premium (value £10).*  
N. W. STORER. "The use of continuous current for terminal and trunk-line electrification."

*An Extra Premium (value £5).*  
A. CAMPBELL & D. W. DYE. "The magnetic testing of bars of straight or curved form."

*An Extra Premium (value £5).*  
A. E. CLAYTON. "The wave-shapes obtaining with alternating current generators working under steady short-circuit conditions."

*An Extra Premium (value £5).*  
Professor G. W. O. HOWE. "The amplitude and phase of the higher harmonics in oscillograms."

In view of the small number of papers read this Session at meetings of the Students' Sections, no Students' premiums have been awarded, but the papers read will be taken into consideration at the next award of Students' premiums.

#### SCHOLARSHIPS.

In view of the absence of a large number of Students on Naval or Military Service, the Council have decided not to award the David Hughes and the Salomons Scholarships this year.

#### STUDENTS' SECTIONS.

Seven meetings of the Students' Section have been held, at which papers were read and discussed. At the opening meeting an address to the Students was delivered by Mr. J. E. Kingsbury, Honorary Treasurer, on "The Institution" (see *Journal*, vol. 54, p. 189, 1916).

The Manchester and Newcastle Students' Sections have each held one meeting.

No meetings of the Scottish Students' Section have been held.

#### MEETINGS OF OTHER SOCIETIES.

During the year, 22 Societies have held meetings at the Institution, as follows:—

No. of meetings.

Associated Municipal Electrical Engineers of Greater London ... ..	11
Electrical Trades' Benevolent Institution ...	4
Incorporated Municipal Electrical Association ...	23
Institution of Post Office Electrical Engineers ...	10
Institution of Railway Signal Engineers ...	6
Post Office Telephone and Telegraph Society ...	8
Röntgen Society ... ..	7
University of London Board of Studies in Electrical Engineering ... ..	2
Wireless Society of London ... ..	1
Thirteen other Societies ... ..	30

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#### LOCAL CENTRES OF THE INSTITUTION ABROAD.

During the year a Local Centre of the Institution has been inaugurated in Hong-Kong, and several meetings have been held.

The formation of a Canadian Local Centre has also been proposed, but in view of present circumstances the Council have thought it advisable to postpone taking further action until the end of the War.

#### LOCAL HONORARY SECRETARIES AND TREASURERS ABROAD.

The following appointments of Local Honorary Secretaries and Treasurers of the Institution abroad have been made by the Council:

Mr. H. Hastings, for Spain, in succession to Mr. A. Jackson.  
Mr. A. C. Kelly, for Argentina, in succession to Mr. E. Danvers.  
Mr. W. M. E. L'Estrange, for Queensland, in succession to Mr. E. G. C. Barton.  
Dr. I. Nakahara, for Japan, in succession to Mr. I. Fujioka.  
Mr. F. W. H. Wheadon, for South Australia, in succession to Mr. C. A. Unbehaun.

The thanks of the Institution are due to Messrs. Barton, Fujioka, Jackson, and Unbehaun, and the late Mr. Danvers, for the valuable services rendered by them to the Institution in promoting its interests.

#### "SCIENCE ABSTRACTS."

The volumes for 1915 contained 1,264 pages, as against 1,296 in 1914, the net cost of the publication to the Institution being £549, as compared with £446 in 1914.

#### WIRING RULES.

A further revision of the Wiring Rules has now been completed, and the Seventh Edition was published in March last. 24 meetings of the Wiring Rules Committee were held during the course of the revision, and upwards of 500 amendments were considered. The new Rules have been adopted by the whole of the Fire Insurance Companies of the United Kingdom. They have also been accepted as standard practice, and their use is recommended by the Incorporated Association of Electric Power Companies, the Incorporated Municipal Electrical Association, the whole of the Electricity Supply Companies of London, and by the principal Supply Companies in the Provinces. 13,500 copies were issued of the Sixth Edition published in 1911.

## EXAMINATIONS.

The last examination of candidates for Associate Membership was held on the 30th April and 1st May, 1915, when entries were received from 2 Students, 6 Graduates, and 1 other candidate who had been offered election as Associate Member provided that he complied with the Examination regulations, the total number of candidates being 9.

Papers were set in 5 non-technical and 4 technical subjects, and the examination was held in London and Manchester concurrently.

One candidate did not present himself, and of the others 5 passed and 3 failed. During the year 6 theses were presented in lieu of the Examination, of which 5 were accepted.

In view of the present circumstances, the Council have decided that during the period of the War and for such further period thereafter as in the opinion of the Council it may be advisable, any candidate for admission as Associate Member who is engaged on naval or military service or employed (whole-time) in an engineering capacity on Munitions or other War work, will be exempted from complying with the Examination Regulations; and any such service may at the discretion of the Council be accepted in part fulfilment of the conditions laid down by the Institution in regard to experience, provided that the candidate satisfies the requirements in respect of age and training.

## RESEARCH.

In July last an announcement was made in Parliament that the Government had included a sum of £25,000 in the Annual Estimates for the promotion of Scientific and Industrial Research. On the invitation of the Committee of the Privy Council, to which the administration of this sum was entrusted, application was made for a grant in aid of the following researches now being conducted or under consideration by the Institution, viz. (a) The Heating of Buried Cables, (b) The Properties of Insulating Oils, (c) Current Densities in Wire, (d) Fibrous Materials (treated and untreated), (e) Porcelain, (f) Ebonite and Mica, (g) Composite Materials, (h) The Properties of Rubber.

Grants have now been received of £840 in respect of (a), and £250 in respect of (b), to cover the cost of a year's work, and the other applications are under consideration.

The Council have appointed Mr. J. S. Highfield, Vice-President, to be the representative of the Institution on the Engineering Committee of the Advisory Council for Research which has been appointed by the Committee of the Privy Council to make recommendations for the allocation of the above-mentioned Government subsidy.

An Interim Report in connection with Tests on Insulating Oils was published in the *Journal*, vol. 54, p. 497, 1916.

## SECTIONAL COMMITTEES.

The five Sectional Committees, namely:—

- (1) Lighting and Power,
- (2) Electric Traction (including Railways, Tramways, and other Means of Transport),
- (3) Telegraphs and Telephones (including Radio-Telegraphy and Railway Signalling),
- (4) Electro-Chemistry and Electro-Metallurgy,
- (5) Electricity in Mines,

have met during the year to arrange for papers on subjects connected with the branches of electrical engineering which they represent.

## NATIONAL SERVICE.

*Members on Naval or Military Service.*

From returns supplied by members it appears that the number of members serving or having served in the Navy or the Army since the outbreak of the War is over 1,300, viz. 129 Members, 585 Associate Members, 66 Associates, 89 Graduates, and 438 Students.

*Commissions in the Signal Service, Royal Engineers.*

Early in December the President at the request of the Authorities nominated a limited number of young electrical engineers for commissions in the Signal Service, Royal Engineers.

*Employment of Disabled Soldiers and Sailors.*

The Council have had under consideration a scheme whereby the Institution may be of assistance in training and finding employment for disabled soldiers and sailors. Letters were sent to a number of electric supply undertakings to ascertain whether they can employ such men, provided that they have received some sort of preliminary training in the duties of sub-station switchboard attendants. Satisfactory replies have been received, and the manner of arranging for the training of these men, obtaining means for carrying out the same, and selecting and distributing applicants for positions is now being considered. A preliminary Guarantee Fund of over £300 has been established for this purpose by past and present Members of Council.

*Institution Rooms.*

From the outbreak of the War until Midsummer 1915 the rooms of the Institution on the first floor were continuously in the occupation of Departments of the War Office and of the Admiralty, free of rent, but in view of the decrease of the Institution revenue it became necessary to ask for some payment for the use of the rooms. The Office of Works have accordingly agreed to become tenants of the Institution, and the Council have sanctioned a reduced rental for this purpose.

## ENGINEERING INSTITUTIONS' VOLUNTEER TRAINING CORPS.

As the result of an invitation received from General Sir O'Moore Creagh, V.C., asking for the Council's co-operation, an Engineering Institutions' Volunteer Training Corps, of which Sir John Snell, Past-President, is Honorary Commandant, was formed last summer of members of the Institutions of Civil, Mechanical, and Electrical Engineers, and other professional men. The corps is affiliated to the Central Association of Volunteer Training Corps, and its Commandant is Lieut.-Colonel C. B. Clay, V.D. The strength of the corps is at present about 120.

## PERIODS FOR REPAYMENT OF MUNICIPAL LOANS.

The representations made by the Council to the Local Government Board in regard to this matter were printed in the *Journal*, vol. 54, p. 63, 1916, together with the reply received from the Board.

## COAL SUPPLIES.

In May last a Conference was held at the Institution of representatives of gas and electricity supply undertakings, to discuss the question of making concerted representations to the Government in regard to the difficulties experienced in connection with coal supplies and prices. Resolutions were carried to call upon the Authorities to take steps to increase the output of coal from the pits, and to give greater transport facilities. A Conference with Members of Parliament took place at the House of Commons early in June, and a deputation attended on the Coal Exports Control Committee and laid before the Committee the views of the gas and electricity supply undertakings. Subsequently, the Coal (Limitation) Act 1915 was passed, in which were embodied clauses to meet the views of these undertakings.

## BENEVOLENT FUND.

The Committee of Management of the Benevolent Fund of the Institution report that on the 31st December, 1915, the Capital Account of the Fund stood at £4,642 3s. The donations and subscriptions to the Fund in 1915 amounted to £777 2s. 7d., including a legacy of £250 from the late Mr. Augustus Stroh.

In the course of the year 7 grants were made amounting to a total of £126.

## ANNUAL ACCOUNTS.

*Excess of Income over Expenditure.*—The margin to the good on the Revenue Account, viz. £1,847 1s., carried to the credit of the General Fund, compares with £1,623 10s. 8d. in 1914.

## Mortgages.—

	£	s.	d.
In the Accounts for 1914 these stood at	34,231	11	0
Amount of repayment during the year	740	5	8
They now stand at	£33,491	5	4

*Life Compositions Fund.*—The total of the Fund on the 1st January, 1915, was £5,409 19s. Out of this the sum of £100 has been transferred to the General Fund, in accordance with the Articles of Association, on account of Life Compositions of members deceased during the year, leaving to the credit of the Fund £5,309 19s.

The whole of this amount is invested in Stock Exchange securities.

*Building Fund.*—This has been augmented during the year by—

	£	s.	d.
Legacy from the late Mr. Augustus Stroh	250	0	0
Donations, Subscriptions, etc.	27	7	6
Contribution out of Institution Revenue	462	18	2
	£740	5	8

the whole of which was utilized in reduction of the Economic Life Assurance Society's mortgage, as shown above.

*Assets.*—Taking the Tothill-street Property and the Investments at cost, and the Institution Building and

Lease, the Library and Furniture, etc., at the values standing in the books after writing off depreciation—

	£	s.	d.
the Assets amount to	116,747	15	10
against Liabilities	43,012	17	2
leaving a balance to the good of	£73,734	18	8

which is made up as follows:—

	£	s.	d.
Building Fund	43,945	16	6
Life Compositions Fund	5,300	19	0
Kelvin Lecture Fund	648	13	0
Foreign Visit Fund	92	14	2
Subscriptions received in advance	127	14	11
General Fund	23,610	1	1

This balance, in comparison with that of

1914 of	71,569	17	4
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shows an improvement for 1915 of £2,165 1 4

## LIBRARY.

Thirty new books have been purchased since April 1915, and 219 books and pamphlets have been presented by members, non-members, and publishers.

The approximate number of volumes in the Institution and Ronalds Libraries is as follows:—

	Volumes
Institution Library (exclusive of Lending Library)	
Text-books, Treatises, etc.	4,269
Periodicals, Transactions of Societies, etc.	5,338
	9,607
Ronalds Library	1,800
	12,407

The total number of readers during the past twelve months was 1,651.

The trustees of the Ronalds Library held their annual meeting, as provided for in the Trust Deed, in February last, and after inspecting the books stated that in their opinion the terms of the Trust Deed had been carried out by the Institution in a satisfactory manner.

During the year, 530 books were issued from the Lending Library to 208 borrowers, the corresponding numbers in the previous year being 602 and 375 respectively.

## FARADAY PAPERS.

The Council have pleasure in stating that, as announced at the Ordinary Meeting of the 18th November, 1915, Mr. D. J. Blaikley, husband of a niece of Michael Faraday, has presented to the Institution a large and valuable collection of Faraday papers and objects to be the subject of a special trust, similar to that under which the Institution holds the Ronalds Library. The papers will be kept together as a separate collection available at reasonable times, not only to the members of the Institution, but to the public on suitable introduction. The thanks of the Council have been expressed to the donor, on behalf of the Institution, for his magnificent gift, and a Trust Deed is in course of preparation.

## MUSEUM.

In response to an appeal by the Council for presentations of historical apparatus sent to the members in June 1915, a number of valuable acquisitions have been made.

H.M. Queen Alexandra has graciously presented an early Bell telephone which was made on H.M.S. *Thunderer* and installed at Marlborough House in 1878, and the following items are among the recent additions to the collection :—

Articles presented	Donor
An early electric motor (designed by O. March)	G. B. Bowell (loan)
A collection of early meters ...	J. Christie (on behalf of the Brighton Corporation Electricity Works)
A collection of sketches drawn by the late E. W. Cooke, R.A., F.R.S., on board H.M.S. <i>Agamemnon</i> (1858)	C. W. Cooke
A Holmes magneto - electric machine	The Corporation of Trinity House
An early Brush arc lamp ...	H. S. Ellis
A Scott patent lampholder (1880)	F. N. Haward
A Siemens dynamometer, and two cut-outs	K. Hedges
A piece of cleat wiring with salt deposit	E. M. Hughman
Three early incandescent lamps (1880-1881)	W. Kingsland
A collection of early meters, etc....	F. Harman Lewis (on behalf of the Leyton Urban District Council Electricity Works)
A piece of "heavy" glass used by Faraday	W. M. Mordey
A Siemens dynamometer ...	T. Blackwood Murray
A specimen of the Malta-Alexandria cable (1808)	E. Pullum (loan)
A collection of early Siemens dynamometers	C. Rodgers (on behalf of Messrs. Siemens Brothers Dynamo Works, Ltd.)
Six Jablochhoff candles and three Cockburn patent fuses	Dr. S. P. Thompson, F.R.S.

## APPENDIX TO REPORT.

## TRANSACTIONS, PROCEEDINGS, ETC., RECEIVED BY THE INSTITUTION.

An asterisk indicates that the receipt of the periodical is at present suspended.

## BRITISH.

Association of Mining Electrical Engineers, Proceedings.  
Association of Supervising Electricians, Proceedings.  
British Association for the Advancement of Science, Reports.  
British Science Guild, Journal.  
Cambridge Philosophical Society, Proceedings.  
Chartered Institute of Patent Agents, Transactions.

Diesel Engine Users' Association, Proceedings in MS.  
Faraday Society, Transactions.  
Greenwich Magnetical and Meteorological Observations.  
Incorporated Institution of Automobile Engineers, Proceedings.  
Incorporated Municipal Electrical Association, Proceedings.  
Institute of Chemistry, Proceedings.  
Institute of Marine Engineers, Transactions.  
Institute of Metals, Journal.  
Institution of Civil Engineers, Proceedings.  
Institution of Engineers and Shipbuilders in Scotland, Transactions.  
Institution of Mechanical Engineers, Journal.  
Institution of Mining and Metallurgy, Transactions and Bulletin.  
Institution of Naval Architects, Transactions.  
Institution of Post Office Electrical Engineers, Papers.  
Institution of Railway Signal Engineers, Proceedings.  
Iron and Steel Institute, Journal and Carnegie Memoirs.  
Junior Institution of Engineers, Journal.  
Liverpool Corporation Tramways, Annual Report.  
Liverpool Engineering Society, Proceedings.  
Manchester Literary and Philosophical Society, Memoirs and Proceedings.  
Municipal School of Technology, Manchester, Journal.  
National Physical Laboratory, Reports and Collected Researches.  
North-East Coast Institution of Engineers and Shipbuilders, Transactions.  
North of England Institute of Mining and Mechanical Engineers, Transactions.  
Physical Society, Proceedings.  
Röntgen Society, Journal.  
Royal Dublin Society, Scientific and Economic Proceedings.  
Royal Institution, Proceedings.  
Royal Meteorological Society, Quarterly Journal.  
Royal Society, Philosophical Transactions and Proceedings.  
Royal Society of Arts, Journal.  
Royal Society of Edinburgh, Transactions and Proceedings.  
Royal United Service Institution, Journal.  
Rugby Engineering Society, Proceedings.  
Society of Chemical Industry, Journal.  
Society of Engineers, Transactions.  
South Wales Institute of Engineers, Proceedings.  
Surveyors' Institution, Transactions and Professional Notes.  
Tramways and Light Railways' Association, Journal.

## COLONIAL.

Australian Official Journal of Patents.  
Canada, Department of Mines, Mines Branch, Reports.  
Canadian Society of Civil Engineers, Transactions.  
Engineering Association of New South Wales, Proceedings.  
Engineering Society of Toronto, Transactions.  
Indian Telegraph Department, Administration Reports.  
Royal Society of Victoria, Proceedings.  
South African Institute of Electrical Engineers, Transactions.  
Western Australian Institution of Engineers, Proceedings.

## AMERICAN (UNITED STATES).

\* American Academy of Arts and Sciences, Proceedings.  
American Electrochemical Society, Transactions.  
American Institute of Electrical Engineers, Transactions and Proceedings.  
American Institute of Mining Engineers, Transactions.  
American Philosophical Society, Proceedings.  
American Society of Civil Engineers, Proceedings.  
American Society of Mechanical Engineers, Journal.  
Bureau of Standards, Washington, Bulletin.  
Engineers' Club of Philadelphia, Proceedings.  
Franklin Institute, Journal.

Illuminating Engineering Society, N.Y., Transactions.  
Institute of Radio Engineers, Proceedings.  
National Electric Light Association, Transactions.  
Smithsonian Institution, Reports.  
U.S. Official Patent Gazette.  
Western Society of Engineers, Journal.

**ARGENTINE.**

Asociación Argentina de Electro Técnicos, Boletín.  
Centro Estudiantes de Ingenieros, Revista.

**AUSTRIAN.**

Kaiserliche Akademie der Wissenschaften, Wien, Sitzungsberichte.

**BELGIAN.**

\* Association des Ingénieurs Electriques sortis de l'Institut Electrotechnique Montehore, Bulletin.  
\* Société Belge d'Electriciens, Bulletin.

**DUTCH.**

Koninklijk Instituut van Ingenieurs, Tijdschrift.  
Koninklijke Akademie van Wetenschappen, Amsterdam, Proceedings.

**FRENCH.**

Académie des Sciences, Comptes Rendus Hebdomadaires des Sciences.  
Bureau des Longitudes, Annuaire.  
\* Société des Anciens Elèves des Ecoles Nationales d'Arts et Metiers, Bulletin Technologique.  
Société des Ingenieurs-Civils, Mémoires.  
Société Française de Physique, Process-verbaux, etc.  
Société Internationale des Electriciens, Bulletin.  
Société Scientifique Industrielle de Marseille, Bulletin.

**GERMAN.**

\* Schiffbautechnische Gesellschaft, Jahrbuch.  
Verein Deutscher Ingenieure, Zeitschrift.  
\* Verein zur Beförderung des Gewerbefleißes, Verhandlungen.

**ITALIAN.**

Associazione Elettrotecnica Italiana, Elettrotecnica.  
Reale Accademia dei Lincei, Atti e Memorie.

**JAPANESE.**

College of Engineering, Kyoto, Memoirs.  
College of Science, Kyoto, Memoirs.

**SWEDISH.**

K. Svenska Vetenskaps-Akademien, Arkiv i Matematik, etc.

**SWISS.**

Schweizer Elektrotechnischer Verein, Bulletin.

# LIST OF PERIODICALS RECEIVED BY THE INSTITUTION.

**BRITISH.**

Beama Journal.  
Cassier's Engineering Magazine.  
Central.  
Colliery Guardian.  
Electric Railway and Tramway Journal.  
Electric Vehicle.  
Electrical Engineering.  
Electrical Industries.  
Electrical Review.  
Electrical Times.  
Electrician.  
Electricity.  
Electrics.  
Engineer.

Engineering.  
Engineering Review.  
English Mechanic.  
Illuminating Engineer.  
Illustrated Official Journal.  
Patents.  
Iron and Coal Trades Review.  
Journal of Gas Lighting.  
Machinery.  
Mechanical Engineer.

\* Mining Journal.  
Nature.  
Page's Engineering Weekly.  
Philosophical Magazine.  
Post Office Electrical Engineers' Journal.  
Railway News.  
Royal Engineers' Journal.  
Tramway and Railway World.  
Vulcan.  
Wireless World.

**COLONIAL.**

Australian Statesman and Mining Standard.  
Canadian Machinery.  
Electrical News (Toronto).  
Power House.

**AMERICAN (UNITED STATES).**

American Journal of Science.  
American Machinist, European Edition.  
Electric Journal.  
Electric Railway Journal.  
Electrical Review.  
Electrical World.  
Engineering Magazine.  
Engineering News.  
General Electric Review.  
India Rubber World.  
Journal of the Telegraph.  
Metallurgical and Chemical Engineering.  
Physical Review.  
Scientific American.  
Telegraph and Telephone Age.  
Telephony.  
Terrestrial Magnetism and Atmospheric Electricity.

**AUSTRIAN.**

Elektrotechnik und Maschinenbau.

**DANISH.**

Teknisk Tidsskrift.

**DUTCH.**

De Ingenieur.

**FRENCH.**

Annales des Postes, Télégraphes, et des Téléphones.  
Archives des Sciences Physiques et Naturelles.  
\* Electricien.  
\* Houille Blanche.  
Industrie Electrique.  
\* Journal de Physique.  
Lumière Electrique.  
\* Mois Scientifique et Industriel.  
\* Portefeuille Économique des Machines.  
\* Revue de l'Ingenieur.  
Revue Electrique.  
\* T.S.F.

**GERMAN.**

Annalen der Physik.  
\* Annalen der Physik, Beiblätter.  
\* Die Antenne.  
Elektrische Kraftbetriebe und Bahnen.  
Elektrotechnische Zeitschrift.  
\* Elektrotechnischer Anzeiger.  
\* Glückauf.  
Jahrbuch der drahtlosen Telegraphie.  
\* Jahrbuch der Radioaktivität.  
Physikalische Zeitschrift.  
\* Zeitschrift für Elektrochemie.  
\* Zeitschrift für Elektrotechnik und Maschinenbau.  
\* Zeitschrift für Instrumentenkunde.  
\* Zeitschrift für Schwachstromtechnik.

**ITALIAN.**

L'Elettricista.  
Elettricità.  
\* Giornale del Genio Civile.  
Il Nuovo Cimento.  
Rivista Tecnica delle Ferrovie Italiane.

**SWEDISH**

Svensk Export.  
Journal Télégraphique.  
Schweizerische Elektrotechnische Zeitschrift.

**THE INSTITUTION OF ELECTRICAL ENGINEERS.**  
**REVENUE ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1915.**

EXPENDITURE.		£ s. d.			INCOME.			£ s. d.
TO MANAGEMENT :—		£	s.	d.	£	s.	d.	£ s. d.
Salaries and Wages (including Staff Provident Scheme) ... ..	...	4,023	5	7	By SUBSCRIPTIONS ... ..	...	...	...
National Insurance ... ..	...	11	18	6	" ENTRANCE FEES ... ..	...	...	...
Accountants' Fees ... ..	...	21	0	0	" BUILDING FUND :—	...	...	...
Printing ... ..	...	274	7	4	Legacy from the late Mr. Augustus Studd ... ..	...	...	...
Stationery and Office Requisites ... ..	...	140	18	2	Donations and Subscriptions ... ..	...	...	...
Addressing Machine Plates ... ..	...	9	3	3	Vellum Diplomas ... ..	...	...	...
Postage of Correspondence and Notices ... ..	...	252	11	9	...	...	...	...
Telephone ... ..	...	48	3	6	...	...	...	...
Travelling Expenses ... ..	...	14	12	2	...	...	...	...
Bank Charges ... ..	...	6	9	10	...	...	...	...
INSTITUTION BUILDING :—		4,811 10 1			...	...	...	...
Ground Rent ... ..	...	2,201	0	0	" DIVIDENDS ON INVESTMENTS ... ..	...	...	...
Rates and Taxes ... ..	...	1,020	8	8	" INTEREST ... ..	...	...	...
Rating and Land Valuation Appeals... ..	...	131	5	0	" WIRING RULES ... ..	...	...	...
Light and Power ... ..	...	74	14	0	" MODEL GENERAL CONDITIONS ... ..	...	...	...
Firing ... ..	...	302	18	7	" INSTITUTION BUILDING :—	...	...	...
Insurance ... ..	...	168	10	11	Rent from Tenants ... ..	...	...	...
Reserve for Repairs ... ..	...	400	0	0	" TOTTILL STREET PROPERTY :—	...	...	...
Household Requisites and Cleaning ... ..	...	110	19	8	Rent from Tenants ... ..	...	...	...
Experimental Lighting of Lecture Theatre and Library Ante-hall ... ..	...	85	13	10	Less Ground Rent, Repairs, Alterations, Rates, Taxes, etc. ... ..	...	...	...
INTEREST ON MORTGAGES		5,305 10 8			...	...	...	...
FURNITURE AND FITTINGS (Repairs and Renewals) ... ..		1,431 6 7			...	...	...	...
JOURNAL :—		31 15 10			...	...	...	...
Printing ... ..	...	1,025	5	7	...	...	...	...
Postage ... ..	...	727	12	11	...	...	...	...
Wrappers and Envelopes ... ..	...	47	11	7	...	...	...	...
		2,400 10 1			...	...	...	...
Less Sales, ... ..		442 15 9			...	...	...	...
LIBRARY (Repairs to old Bindings) ... ..		1,057 14 4			...	...	...	...
LESSING LIBRARY (Books, Printing, Postage, etc.) ... ..		117 0 10			...	...	...	...
MUSEUM ... ..		43 6 11			...	...	...	...
Carried Forward ... ..		24 18 5			...	...	...	...
		£13,813 3 8			...	...	...	£18,870 2 1

REVENUE ACCOUNT—*continued*.

Dr.	EXPENDITURE— <i>continued</i> .		INCOME— <i>continued</i> .		Cr.
	£	s. d.	£	s. d.	
Brought Forward	...	...	...	...	Brought Forward
To NATIONAL SERVICE (Coal Supplies, Volunteer Training Corps, etc.)	...	13 11 3	...	...	
EXAMINATIONS	...	...	...	...	
SCIENCE ABSTRACTS :—	...	...	...	...	
Salaries, Abstracting, Printing, Postage, etc.	...	18 7 2	...	...	
Loss Subscriptions, Sales, and Advertisements	...	13 13 10	...	...	
MEETINGS :—	...	...	...	...	
Advance Proofs	...	43 16 10	...	...	
Reporting	...	50 8 0	...	...	
Honorarium to Kelvin Lecturer	...	25 0 0	...	...	
Refreshments, Assistance, etc.	...	74 2 3	...	...	
LOCAL SECTIONS :—	...	...	...	...	
Money Grants	...	678 7 5	...	...	
Travelling Expenses	...	154 4 1	...	...	
PREMIUMS	...	...	...	...	
ENGINEERING STANDARDS COMMITTEE	...	...	...	...	
RESEARCH COMMITTEE	...	...	...	...	
INTERNATIONAL ILLUMINATION COMMISSION	...	...	...	...	
LEGAL EXPENSES	...	...	...	...	
MISCELLANEOUS EXPENSES	...	...	...	...	
AMOUNTS TRANSFERRED TO :—	...	...	...	...	
Building Fund (Obligatory repayment to Economic Life Assurance Society) :—	...	...	...	...	
Donations, Subscriptions, etc. ( <i>per contra</i> )	...	£277 7 6	...	...	
Contribution out of Revenue	...	402 18 2	...	...	
SINKING FUND (Premiums for Redemption of Cost of Building and Lease)	...	740 5 8	...	...	
GENERAL FUND :—	...	...	...	...	
Expenditure on—	...	...	...	...	
Books and Binding for Library	...	79 18 3	...	...	
Balance, being unexpended Revenue for the Year 1915	...	1,847 1 0	...	...	
	...	2,041 17 1	...	...	
	...	£18,670 2 1	...	...	

£18,670 2 1

## BALANCE SHEET, 31ST DECEMBER, 1915.

## LIABILITIES.

## ASSETS.

£.

To BUILDING FUND:—		£	s.	d.
Balance at 1st January, 1915	...	43,205	0	10
Donations, Subscriptions, etc.	...	277	7	6
Contribution out of Revenue	...	402	18	2
		43,885 10 6		
" ECONOMIC LIFE ASSURANCE SOCIETY:—				
On Mortgage of Institution Building (1909)	...	2,000	0	0
Since repaid	...	4,068	14	8
		21,971 5 4		
On Mortgage of Tothill Street Buildings and Site (1910)		...	11,500	0
		33,491 5 4		
" LIFE COMPOSITIONS FUND:—				
Balance at 1st January, 1915	...	5,409	10	0
Less Life Compositions of Deceased Members transferred to General Fund	...	100	0	0
		5,309 10 0		
" KELVIN LECTURE FUND:—				
As per last Balance Sheet	...	802	10	10
Less Loss on conversion of £1,000 2½% Consolidated Stock into £600 2s. 4½% War Stock	...	213	17	10
		648 13 0		
" TRUST FUNDS CAPITAL ACCOUNTS:—				
Solomons Scholarship	...	2,126	10	3
David Hughes Scholarship	...	2,000	0	0
Wide Benevolent Fund	...	1,840	4	6
		5,973 3 9		
" TRUST FUNDS INCOME ACCOUNTS:—				
Balances unexpended:—				
Solomons Scholarship	...	38	10	4
David Hughes Scholarship	...	279	9	6
Wide Benevolent Fund	...	40	0	5
		208 15 3		
Invested Income (Wide Benevolent Fund)	...	...	...	...
FOREIGN VISIT FUND	...	...	...	...
" SUNDRY CREDITORS	...	...	...	...
" SUBSCRIPTIONS RECEIVED IN ADVANCE	...	...	...	...
Carried Forward	...	...	...	...

By INSTITUTION BUILDING AND LEASE:—		£	s.	d.
Cost	...	...	73,028	6 10
Less Reserve for Depreciation, being Sinking Fund Premiums paid	...	...	18,819	8
		71,179 7 2		
" TOTHELL STREET BUILDINGS AND SITE (at cost)		...	...	...
" SINKING FUND (Premiums paid for Redemption of Cost of Building and Lease)	...	...	...	...
" LIFE COMPOSITIONS INVESTMENTS (at cost):—				
£2,000 Natal Zuluand Railways 3½% Debentures	...	2,270	12	0
£1,500 Lancashire and Yorkshire Railway 4%	...	1,513	10	4
Preference Stock	...	1,548	0	6
£2,000 Assam Bengal Railways 3% Stock	...	5,332	2	10
		9,688 13 0		
" KELVIN LECTURE FUND INVESTMENT (at cost):—				
£600 2s. 4½% War Stock	...	...	...	...
" TRUST FUNDS INVESTMENTS (at cost):—				
Solomons Scholarship:—				
£1,500 New South Wales 3½% Stock	...	1,556	5	0
£500 Cape of Good Hope 3½% Stock	...	570	13	6
		2,126 10 3		
David Hughes Scholarship:—				
£204½ Solomons Reservoirs 3% Guaranteed Debenture Stock	...	...	1,998	15 0
Wide Benevolent Fund (Capital Account):—				
£875 Great Eastern Railway Metropolitan 5% Guaranteed Stock	...	1,493	16	3
£215 North Eastern Railway 4% Guaranteed Stock	...	230	10	0
£100 London County 3½% Stock	...	101	8	6
		1,840 4 6		
Wide Benevolent Fund (Income Account):—				
£250 New South Wales 4% Stock	...	251	6	0
£100 3½% War Stock	...	94	8	8
		345 14 8		
" LIBRARY:—				
As per last Balance Sheet	...	1,395	3	8
Additions in 1915	...	79	18	3
		1,475 11 11		
Less Depreciation (10%)	...	147	6	2
		1,328 15 9		
Carried Forward	...	...	...	...

\* Exclusive of the Readable Library which is held on trust.

## BALANCE SHEET—continued.

Dr. LIABILITIES—continued.

ASSETS—continued.

£ r.

	£	s.	d.	£	s.	d.
Brought Forward	...	...	...	...	...	...
TO REPAIRS, STIMULUS ACCOUNT:—						
Amount set aside in 1915	...	...	...	...	...	...
Less Balance (as per last Balance Sheet)	...	...	...	...	...	...
Expenditure on Repairs in 1915	...	...	...	...	...	...
	329	5	2			
	...	...	...	...	...	...
GENERAL FUND:—						
Balance at 1st January, 1915	...	...	...	...	...	...
Life Compositions of Deceased Members	...	...	...	...	...	...
Expenditure in 1915 on—						
Books and Binding for Library	...	...	...	...	...	...
Unexpended Revenue for 1915	...	...	...	...	...	...
	238	5	16			
Less Depreciation (per contra):—						
Library	...	...	...	...	...	...
Furniture, Fittings, and Apparatus	...	...	...	...	...	...
	276	15	0			
	...	...	...	...	...	...
	70	14	10			

£110,747 15 10

J. E. KINGSBURY,  
Honorary Treasurer,  
P. F. ROWELL,  
Secretary.

We beg to report that we have audited the Balance Sheet of the Institution of Electrical Engineers, dated 31st December, 1915, and above set forth, together with the annexed Statements of Account. We have obtained all the information and explanations we have required. In our opinion the Statements are correct, and the Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Institution's affairs according to the best of our information and the explanations given to us and as shown by the books of the Institution.

ALLEN, ATTFIELD AND CO.,  
Chartered Accountants,

10th March, 1916.  
147, LEADENHALL STREET, E.C.6.

SIDNEY SHARP,  
Honorary Auditor.

£110,747 15 10

1,809 6 6

4,407 11 7

1,770 13 4

1 5 0

28 8 2

## SALOMONS SCHOLARSHIP TRUST FUND (Income).

Dr.	£ r.	
	£	s. d.
To Amount paid to Scholars in 1915	...	50 0 0
" Balance carried to Balance Sheet	...	38 16 4
	<u>£88 16 4</u>	
	£	s. d.
By Balance (as per last Account)	...	18 10 4
" Dividends received in 1915	...	70 0 0
	<u>£88 16 4</u>	

## DAVID HUGHES SCHOLARSHIP TRUST FUND (Income).

Dr.	£ r.	
	£	s. d.
To Amount paid to Scholars in 1915...	...	12 10 0
" Balance carried to Balance Sheet	...	79 9 6
	<u>£91 19 6</u>	
	£	s. d.
By Balance (as per last Account)	...	30 12 6
" Dividends received in 1915	...	61 7 0
	<u>£91 19 6</u>	

## WILDE BENEVOLENT TRUST FUND (Income).

Dr.	£ r.	
	£	s. d.
To Balance carried to Balance Sheet	...	90 9 5
	<u>£90 9 5</u>	
	£	s. d.
By Balance (as per last Account)	...	21 5 5
" Dividends received in 1915	...	67 16 6
" Interest do.	...	1 7 6
	<u>£90 9 5</u>	

# THE BENEVOLENT FUND OF THE INSTITUTION OF ELECTRICAL ENGINEERS.

## INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR 1915.

### EXPENDITURE.

### INCOME.

£*r*.

	£	s.	d.
To Grants	126	0	0
" Printing Stationery, and Postage	21	18	0
" Unexpended Balance carried to Balance Sheet	812	19	4
	<u>£960</u>	<u>17</u>	<u>4</u>

	£	s.	d.
By Dividends on Investments...	...	...	...
" Interest on Deposit ...	...	...	...
" Annual Subscriptions	...	...	...
" Donations of £5 and over ...	...	...	...
" Donations under £5	...	...	...
" Legacy from the late Mr. Augustine Strick	...	...	...
	<u>£960</u>	<u>17</u>	<u>4</u>

## BALANCE SHEET, 31ST DECEMBER, 1915.

### LIABILITIES

### ASSETS.

£*r*.

	£	s.	d.
To Capital (as per last Balance Sheet)	...	...	...
" Income and Expenditure Account :—	...	...	...
As per last Balance Sheet	£880	17	0
Unexpended Balance in 1915	812	19	4
	<u>1,493</u>	<u>16</u>	<u>4</u>
" Sundry Creditors	...	...	...
	<u>6</u>	<u>5</u>	<u>0</u>

	£	s.	d.
By Investments (Capital, at cost :—	...	...	...
£961 7s. 7d. Cape of Good Hope 3 % Stock	...	...	...
£593 1s. 7d. New South Wales 3 % Stock	...	...	...
£420 Great Eastern Railway 4 % Preference Stock	...	...	...
£600 North Staffordshire Railway 3 % Debenture Stock	...	...	...
£750 East Indian Railway 3½ % Debenture Stock	...	...	...
£300 London and North-Western Railway 4 % Guaranteed Stock	...	...	...
£500 New Zealand 3½ % Stock	...	...	...
£500 Canada 3½ % Stock	...	...	...
	<u>4,042</u>	<u>3</u>	<u>0</u>

" Investments (Income), at cost :—

	£	s.	d.
£350 New South Wales 4 % Stock	...	...	...
£200 War Stock 3½ %	...	...	...
£300 War Stock 4½ %	...	...	...
	<u>1,023</u>	<u>2</u>	<u>3</u>
" Sundry Debtors	...	...	...
" Cash :—	...	...	...
At Bankers'...	...	...	...
In hand	...	...	...
	<u>£6,142</u>	<u>4</u>	<u>4</u>

£6,142 4 4

We have audited the above Balance Sheet and Income and Expenditure Account with the Books and Vouchers and certify them to be correct. The Investments have been verified by Bankers' Certificates. They are stated at cost, which is, however, subject to depreciation since date of purchase.

JAS. ATTFIELD, F.C.A. }  
SIDNEY SHARP } *Honorary Auditors.*

13th April, 1916.

## HIRE AND MAINTENANCE OF CONTINUOUS-CURRENT MOTORS.

By HENRY JOSEPH, Associate Member.

(Paper first received 22 October, 1915, and in final form 11 April, 1916; read before the YORKSHIRE LOCAL SECTION 8 March, and before the WESTERN LOCAL SECTION 3 April, 1916.)

The electricity-supply undertaking of which the author has charge having carried on a small but successful business in the hire of motors for the past 14 years, it may be of interest to members if some particulars are published.

The company supplies continuous current, principally for textile driving, in the town of Hawick in Roxburghshire, the main industries of the district being the manufacture of tweed and hosiery.

Table 1 shows the proportion of motors on hire at the end of 1915 in mills and for various industrial purposes.

TABLE 1.

	No. of Motors	Total h.p.	Average h.p.
Consumers' own motors...	174	1,066	6.3
Motors on hire-purchase...	10	451	45.1
Motors on hire ... ..	116	731	6.3
Totals ... ..	300	2,278	7.6

Practically the whole of the above motors are maintained by the author's staff; and most of those owned by consumers have been supplied through the company and the drive arranged under their supervision.

## HIRE TERMS.

Table 2 gives the present rates of hire.

TABLE 2.

## Standard Hire Rates.

Horse-power	Quarterly Rental	Horse-power	Quarterly Rental
$\frac{1}{4}$	£ 5 d.	$\frac{1}{2}$	£ 15 0
$\frac{1}{2}$	0 9 0	$\frac{3}{4}$	2 15 0
$\frac{3}{4}$	0 15 0	1	3 2 6
1	1 0 0	10	3 5 0
2	1 5 0	12	3 7 6
2½	1 10 0	15	3 10 0
3	1 15 0	18	4 0 0
3½	1 17 6	20	4 5 0
4	2 0 0	25	4 10 0
5	2 5 0	30	4 12 6
6	2 7 6	40	5 2 6
7	2 12 6	50	6 5 0

These rates have been considerably increased from those of the early days, since the original terms were found to be inadequate. At first, quotations were given for the

hire of motors after the cost of each installation had been calculated. During the past four or five years it has been found more convenient to adopt a definite rate per horse-power for standard motors. Special motors, such as low-speed or geared ones, are not let on hire unless they happen to be in stock.

The hire rate includes the motor complete with pulley, starter, main switch, cut-outs, shunt regulator, and slide rails, if these are required, all fixed and connected up. The hirer pays for belting and the cost of mains from the service (or from the nearest available point of supply) to the motor and starter. The result is that practically the whole of the material is returnable on dismantling and only the cost of labour is lost.

The rental covers the cost of all maintenance and renewals. New brushes are fitted when required, and no question as to whether the company is liable ever arises in the event of a breakdown. Damage occasionally occurs as the result of carelessness or negligence on the part of the hirer's employees, but it has not been considered good policy to raise the question of liability in such cases. They do not often occur, and the inconvenience caused to the user by a breakdown is quite sufficient incentive as a rule for him to urge his employees to treat the motor carefully.

It is to this policy, coupled with prompt attention to repairs, that the success of the hire system is largely due. Consequently consumers are quite willing to pay in most cases rentals which are admittedly high in comparison with the purchase price of the motors.

The company safeguards itself against loss due to a motor being hired for a short period and then returned, by inserting a clause in the hire agreement by which the hirer undertakes to pay an agreed sum to cover the cost of installation and removal in the event of a motor being returned before the expiration of a stated period.

It may be urged that the scale of charges is not quite proportional to the usual cost of motors of various makes, and that the rental is a higher percentage of the cost of the smaller motors. This is so, but the maintenance of a small motor is always relatively more costly, for reasons which will be readily understood.

Motors up to 10 or 12 h.p. are much more liable than larger machines to armature breakdowns, partly on account of the small size of the conductors. The field coils of small motors are as a rule more liable to injury from damp or oil. They are less accessible and cannot be so easily or thoroughly cleaned, and they are often so near the magnet frame that dirt gets lodged between the coils and the iron. Minor troubles with brush-gear, etc., are relatively much more expensive in small motors than in large ones.

One might reasonably expect that motors would only be hired by small firms with limited capital, but this is by no means the case. Nearly all the hosiery mills, among them some of the largest in Scotland, hire their motors.

They prefer to confine their attention to their business and to hand over the whole responsibility of their electric drive to the supply company.

Consumers possessing their own motors are encouraged to insure them against breakdown. In a few cases the company has undertaken such insurance, but this policy is not persisted in. They are now usually advised to insure them with an insurance company whose rates are quite moderate, but in comparing their premiums with the supply company's hire charges one has to bear in mind that the former indemnifies the user against breakdown pure and simple, whereas the latter under their hire terms undertakes maintenance, supply of brushes, and the replacement of the motor or any parts that may be worn. In the event of a minor breakdown, a man is promptly on the spot to carry out repairs on site if possible. If the trouble cannot be quickly remedied another motor is fixed as quickly as possible. For mill work these are important considerations.

#### FINANCIAL RESULTS.

Table 3 shows the number and horse-power of motors let on hire each year since 1902, with the corresponding capital cost and rental per horse-power.

TABLE 3.

Year	Added in Year		Total to Date		Average h.p.	Per horse-power	
	No.	h.p.	No.	h.p.		Capital Cost	Yearly Rental
1902	5	16	5	16	3.2	£14.0	12.1
1903	29	50	34	72	2.3	15.3	20.6
1904	10	101	44	173	4.2	10.5	15.8
1905	10	50	54	220	4.5	10.7	17.1
1906	8	39	62	268	4.5	10.5	22.5
1907	0	44	68	312	4.6	10.2	22.4
1908	5	31	73	343	4.7	9.3	22.0
1909	14	58	87	401	4.6	8.5	23.4
1910	6	20	93	421	4.5	8.1	20.5
1911	10	126	103	547	5.3	7.0	24.0
1912	3	—	106	542	5.1	7.0	25.0
1913	4	92	110	634	5.7	6.2	22.0
1914	—	0	105	643	6.1	6.0	23.2
1915	7	78	112	721	6.4	5.4	22.2

The former shows a steady fall owing to the lower prices of motors, the higher average horse-power, and the fact that as time goes on some motors are in use which have been hired out before and consequently have had their cost written down. Mains and other incidental charges were included in some of the earlier installations, thus further enhancing the capital cost.

Table 4 gives the total capital cost to date, with the corresponding maintenance costs and gross and net rentals for each year since 1902.

It will be noticed that, ignoring occasional years when exceptional conditions may have prevailed, there is a gradual increase in the percentage cost of maintenance due to the ageing of the bulk of the motors. This figure will probably settle down to an average of about 6 per cent on the capital cost.

During the last five years the gross rentals amounted to about 18 per cent of the capital outlay, the lower rates received from the earlier motors having reduced this from about 25 per cent, which is the average rental obtained on the total cost with new motors during this period. Taking

TABLE 4.

Year	Capital Cost to Date £	Gross Rentals		Maintenance		Net Rentals	
		£	Per cent	£	Per cent	£	Per cent
1902	232	10	4.2	—	—	10	4.2
1903	1,100	74	6.8	2	0.2	72	6.6
1904	1,824	137	7.5	14	0.8	123	6.7
1905	2,432	190	8.1	34	1.4	162	6.7
1906	2,807	301	10.7	52	1.8	250	8.9
1907	3,471	350	11.0	137	4.3	213	6.7
1908	3,197	378	11.8	122	3.8	256	8.0
1909	3,431	469	13.7	116	3.4	353	10.3
1910	3,425	621	18.1	146	4.3	475	13.8
1911	3,820	655	17.1	274	7.2	381	9.9
1912	3,770	680	18.0	205	5.4	475	12.6
1913	3,903	607	17.7	250	6.4	447	11.3
1914	3,861	745	19.3	214	5.5	530	13.8
1915	3,881	802	20.6	243	6.2	559	14.4

the former figure and deducting 6 per cent for maintenance, we are left with a net rental of about 12 per cent, part of which is allocated to revenue and the balance set aside to a redemption fund for writing down the value of the motors when returned from hire.

#### EQUIPMENT.

The motor store and repair shop consists of a substantial wooden shed 30 ft. long, 16 ft. wide, and 9 ft. 6 in. high to the eaves. Adjoining it is a lean-to store 30 ft. by 14 ft. The floor is of concrete 3 in. thick on a hard bottom, and a double row of railway sleepers chamfered on both edges so as to dovetail into the concrete are laid down flush with the floor for fixing down motors for testing purposes. A 2-ton overhead travelling crane is installed, cupboards and pigeon holes for insulating material, spares, and starters, being fitted round the walls. Spare pulleys are kept on inclined tubes projecting from the walls, each tube holding four or five pulleys of one diameter but of different widths and bores. The equipment of the shop unfortunately does not include a lathe, but armatures are easily transferred on a low bogie to the workshop adjoining the engine room, where there is a lathe available for turning up commutators or belting armatures.

The equipment of the motor shop includes a bench with a couple of vices, and a lower bench to take an armature on a pair of portable stools. These, together with the cupboards and pigeon holes, are on one side and the far end, the opposite side being kept clear for the storage of motors. There are a pair of large doors on the front end to allow a cart or motor lorry to back in under the crane.

Over the armature bench is a set of resistance units in parallel, each being capable of being cut out by means of a switch, and the whole being broken at a pair of terminals to allow of testing currents from 0.20 to 20 amperes being used.

The adjoining lean-to building contains various stores other than motors, starters, regulators, pulleys, etc., which are needed in connection with motor work.

It is most essential that proper tackle should be at hand for carrying out with as little delay as possible whatever operations are needed. This tackle includes shear-legs, handcrats, a 5-wheel bogie, two or three chain blocks for light or heavy lifts, pinch-bars, rope slings, battens, spanners, pulley drawers, etc., each kept in a definite place ready for taking out on to a job.

#### STOCKS.

The following stocks of motors, etc., are usually kept on hand. They represent a fair average, though frequent changes sometimes lead temporarily to a depletion of one size and an overstock of another.

Motors		Starters	
No.	Horse-power	No.	Horse-power
1	40 to 50	1	80
2	30	2	40 to 50
3	20	3	30
4	15	4	20
5	10	5	15
6	7½	6	10
7	5	7	7½
8	4	8	5
9	3	9	3
10	2	10	2
11	1	11	1
12	¾	12	¾

*Shunt regulators.*—Twelve, from 0·15 ampere to 3·5 amperes (maximum).

*Pulleys.*—Sixty, from 3 in. to 15 in. diameter.

In addition to the above a stock has to be kept of every size and type of brush in use in the town, both on consumers' own and hired motors. There are over 40 of these and they are each given a number, which is also painted in large figures on the motor frame. These numbers are used both for ordering new brushes and to facilitate the sending of the correct ones to consumers.

#### CARD SYSTEM.

The card system in use is illustrated in the adjoining column. On the front of the card at the top are particulars of the motor. Underneath are six spaces for entries of particulars of various drives on which the motor has been used (quite a number of these cards are full up, the motors in question having been on six or more drives, perhaps some of them temporarily during repairs to other motors).

On the other side any repairs or other incidents in the history of the machine are noted.

#### BREAKDOWNS.

Before describing the procedure in the event of a breakdown, it is well to point out that the company act as wiring contractors and always have a staff of wiremen available. The permanent wiremen and mains staff are

all trained for motor work, and one man in particular spends most of his time on motor repairs and is as often as not in the works and readily available for emergency calls.

Type	.....
H.P.	..... Speed..... Vols.....
Motor No.	..... Armature No.....
Type of Starter	.....
Pulley	..... Brushes.....
Com. No.	Name Address Driving
Com. No.	Name Address Driving
Com. No.	Name Address Driving
Com. No.	Name Address Driving
Com. No.	Name Address Driving
Com. No.	Name Address Driving

*Changing a motor.*—If a report of a breakdown is received, a man is sent out at once and reports by telephone if the failure is such that it cannot be repaired quickly on site. In that case he sets to work to get the faulty motor disconnected and removed from its bed. Particulars of the drive at the same time are ascertained at the works and a suitable motor selected from stock. Sometimes one can be found, perhaps larger than is necessary, but which is already fitted with a pulley near enough to the right size. If a little too small, a temporary shunt regulator may be fitted.

Of course it is impossible to stock all possible varieties of pulleys of various diameters and bores, consequently it frequently happens that a stock pulley has to be bored out or bushed and a new key-way cut. If this is necessary it is put in hand at once and fitted after the motor is in place.

A motor or horse lorry is ordered, preferably the former, several being available for hire in the town, and the motor is slung up and very little time lost in getting it on site.

Battens are taken to the job with it, and as the old bolt

centres are probably wrong it may be necessary to screw battens down with the old foundation bolts (if these are set in concrete), recessing the heads below the surface of the battens and coach-screwing the motor down to them. Usually, however, motors are already fixed on battens wide enough to allow of considerable variation in bolt centres, so that little time is lost in fixing down another motor to them.

As a motor is often fixed in a room which can only be reached by taking it up two or three flights of stairs, a good deal of experience and some ingenuity is needed in handling it quickly and safely. For this purpose a U-shaped clamp with a set-screw is used to fix a chain block to a joist, or else a hole is bored through a floor and an eye bolt with a large washer fixed. If the staircase is an open one it is easy to "sling" a motor from floor to floor, otherwise a pair of long battens are laid down on the stairs and the motor slid up them by hauling with a chain block. Sometimes in the case of small motors, up to say 5 h.p., it is quickest to remove both end shields and take out the armature, when the motor can be carried up in pieces.

In the case of larger motors one has often to contend with such difficulties as rolling them across weak wooden floors in a mill. Long battens are kept in the stores for such purposes in order to distribute the weight over the floor. With constant experience in this kind of work one gets into the way of improvising simple devices for particular cases.

Great delay has often occurred in the past in removing pulleys. These are sometimes made to fit the shaft too tightly and are driven on hard. They are best shifted with a pair of screw pulley drawers. Keys also are a fruitful source of delay, and to obviate this they are now always fitted with gib heads. One or two types of key drawer have been tried, but with varying success. If keys and pulleys are only fitted properly in the first place and a film of oil put on the shaft, very little trouble is likely to be found in removing them again.

In many cases, e.g. where pulleys, etc., give no trouble, a small motor up to say 5 h.p. can be changed in an hour and a half from the time of the breakdown, but possibly a more useful period from the notification of stoppage to the time a new motor is running is double this.

Large motors cannot of course be handled nearly so quickly. There is less likelihood of pulleys being right, owing to there being fewer motors to choose from; moving is less rapid in the mill, and time is lost in taking on and off heavy belts; but by having men working simultaneously on the old and new motors while at the same time the pulley is being prepared, if necessary it is by no means impossible to change a 30-50-h.p. motor in  $2\frac{1}{2}$  to 3 hours.

**Repairs on site.**—A man having been called to a motor sets to work at once to find if the trouble is due to the starter or any part of the switchgear, or to the armature, field, brush-gear, or wiring. The majority of stoppages are due to starter troubles, and of these the bulk are caused by burnt-out resistances or open-circuited hold-over coils, these fairly frequently failing at the leading-in wires. Most starter defects can be remedied, at any rate temporarily, on site. If not, a fresh starter is telephoned for. In the case of a large motor it is usually quicker to repair a fault on a field coil on site than to change the motor. It means of course removing one end, taking out the arma-

ture, and perhaps removing a pole-piece to get the coil out. By cutting away the outer tape before dismantling one can usually judge as to whether the trouble is sufficiently near the surface for a fairly quick repair to be possible. If the breakdown occurs in the afternoon a large motor is never changed for a field-coil repair unless it is a genuine burn-out.

In the case of armature faults it is often possible to make a temporary repair on site which will keep the motor running until a week-end. The commonest fault, especially in small armatures wound with fine-gauge conductors, is a break at the point where one of the ends bends away from the coil. One can frequently get over this in lap-wound armatures by soldering across the commutator lugs.

#### TYPICAL BREAKDOWNS.

A few typical cases of breakdown may be instanced.

(1) *Commutator broken down to earth.*—On taking off the commutator ring it is found to be charred at one place and a shallow hole burnt nearly through it. The best plan is to dovetail a piece of mica neatly into the place, having carefully cut away the burnt portion and fitted the new piece which is held in place with shellac varnish. "Plas-mica" and some of the similar materials on the market are very useful for filling up small holes burnt in commutator insulation.

(2) *Bearing seized, while metal run out and armature let down on to pole-pieces.*—Sometimes this leads to the conductor being cut partly through and to a complete re-wind being necessary. Especially is this liable to happen if the motor is driving machinery with considerable inertia. More usually some of the belts are cut through and the conductors unharmed. One should never neglect to look to the bearings for the trouble where a band is found coiled up between the armature and the pole-pieces for no apparent reason.

(3) *A short-circuited coil.*—A temporary repair sufficient to keep a motor running at a moderate load till shutting-down time can often be effected by simply cutting out the faulty coil and bridging across adjacent commutator bars, always provided that the armature is a parallel-wound one. It is inadvisable to let a motor run too long in this condition as the trouble is apt to spread.

In one or two instances the spaces between the radial bars have been found to be filled up tight with grease and fluff from the wool, and this has broken down and short-circuited the coils, necessitating a re-wind.

Fairly often troubles occur on a badly designed brush-gear through the springs failing to follow up adequately the wear on the brush, causing the latter to chatter and come out.

Field coils suffer not infrequently through an accumulation of oil in the motor case rotting either the bottoms of the lower fields themselves or the field connections.

Breakdowns have occurred to field coils through the ferrule insulation perishing through the combined effect of heat and age. These troubles often show themselves when a motor has been moved, the insulation cracking and the winding earthing through the ferrule on to the core.

#### REPAIRS.

The surest way to keep down the cost of repairs is to educate one of the hirer's employees to keep the motor

clean and the armature and field coils blown free from dust, to see that brushes do not wear down too far, and to keep a proper level of clean oil in the bearings. As a breakdown entails interruption of the user's business he will usually see that one man is made responsible for a particular motor and that he gives it ten minutes or so of attention, say, once a week.

*Inspection.*—It was at one time thought that periodic inspection would lead to a diminution of breakdowns, but this after being tried was abandoned. Such inspection, to be thorough, was a lengthy business; visits could only be made at fairly long intervals of time, and breakdowns occurred just the same between visits. Financially it has been found more advantageous to risk a motor running till it fails, than to inspect 20 or 30 motors on the chance of detecting one which needs attention. When the company's men are working in a mill they examine any motors in the particular section in which they are at work and report if they observe anything out of order. Otherwise, reliance is placed on reports of unsatisfactory operation from the users.

Although in most cases motors are kept fairly clean there are occasional instances of their being allowed to run without any attention whatever. A year or two ago instructions were received to attend to a 10-h.p. motor in a joiner's shop. The machine belonged to the joiner and he had such faith in it that he had never touched it since it was installed, that is to say for a period of nine years. The fuses had blown and it was found that the case was completely full of oily sawdust which had wedged itself so tightly between the core and the pole-pieces that the fuses blew from overload. The motor was quite unharmed and had merely to be taken to pieces and thoroughly cleaned.

*General overhaul.*—When a hired motor needs general overhaul the following procedure is adopted.

It is taken entirely to pieces, the commutator turned, the mica recessed, and the armature and field coils varnished with a suitable insulating varnish. Bands are inspected and if at all slack are replaced, and fresh whip-cord if necessary wound on. Bearings are inspected and re-white-metalled if necessary, or in the case of bushes new ones fitted if required or the old ones lined with white-metal. The brush-gear is taken to pieces and overhauled, and the frame thoroughly cleaned with petrol and finally painted. The colour is a grey, but the actual shade is changed each year thus giving a rough guide as to how long a motor has run since the last overhaul. Finally, the machine is run for 8 hours at full load driving another motor as a dynamo, and if satisfactory it is ready to be sent out again. It is believed that by sending out a motor smartly painted and looking like new it is likely to receive more careful attention than if issued in a shabby condition. There seems to be no doubt that the user takes a pride in keeping it in good condition.

*Re-winding armatures.*—When a re-wind is necessary it used to be the practice to send the armature away, but now the repair is usually done at the works, the necessary coils being bought from the makers.

The question frequently arises as to whether in a particular case it pays to re-wind rather than replace one or two faulty coils. It is very annoying after fitting a couple of coils to find that another has been damaged in lifting. It is still more provoking if the second failure does not

occur until the armature has been belted and the motor re-assembled and tested. If the original faulty coils have been overheated to such an extent as to be useless as a guide to the condition of the rest, it is probably a good plan to scrap an additional coil and bend the wire to see if the cotton is perished and breaks easily. If so, it should certainly be re-wound, because the coils which have to be lifted are almost certain to be damaged during the process. The exact point at which one may feel justified in confining the repair to the replacement of a few coils can only be judged by experience.

It is unnecessary to go into details as to the methods of repair as these are familiar to any armature winder.

Armatures should of course have a preliminary fall-of-potential test before the ends are sweated into the commutator. In connection with voltage-drop tests generally, the author would draw attention to what he believes is a fairly common error, namely, putting the current leads on opposite ends of a diameter or separated by an angle corresponding to the brush positions. If this is done and there are equalizing connections, confusion is apt to arise, especially if, as is sometimes the case, one or more equalizing wires are broken. If the current leads as well as the millivoltmeter leads are both applied to adjacent bars, the effect of possible trouble with equalizing connections is eliminated.

*Repairs to field coils.*—Quite successful repairs have been carried out to shunt field-coils that have started to burn out but have been detected before very serious damage has been done. A number of turns may be entirely taken off to eliminate the fault. If the quantity of wire removed is an appreciable proportion of the total, a new length is wound on and jointed by means of a sleeve with binding screws. It is considered advisable to avoid soldered connections in a field if possible, and the old wire is cut back to enable the connector to lie against the ferrule, great care being taken in insulating it. Occasionally in an emergency where a large motor cannot be easily replaced, a burn has been cut out, leaving quite a number of ends to be joined up. These are tested out and must inevitably be soldered. One or two motors with fields repaired in this way have since run for considerable periods without any further trouble. Such jobs need considerable patience. The soldered joints are insulated from the adjacent turns with mica.

*Effect of cutting mica on the cost of brushes.*—While on the subject of repairs one cannot lay too much stress on the importance of recessing the mica below the surface of the copper on the commutator. The saving in brushes is most marked, and in a few instances in particular it is little short of astonishing. Motors which have been known to consume a set of brushes in three weeks will go for 12 months without a single new one. The wear on the commutator in such cases before this treatment is of course excessive.

Table 5 gives the annual cost of carbon brushes for the past 10 years, together with the corresponding percentage of capital to date and the cost per horse-power and per motor.

It is only during the last four years that a general rule has been made of recessing the mica as a means of curing all motors which are liable to spark badly. This process took some time and it was probably well into 1914 before

all the worst cases had been dealt with. Consequently, the improvement in costs which is best seen in the last column is gradual since 1911, but it is very marked. Part

TABLE 5.  
*Annual Cost of Brushes.*

Year.	Cost of Brushes.	Percentage of Capital to Date.	Cost per Horsepower.	Cost per Motor.
	£ s d		£ s d	
1906	10 11 1	0.50	8 8	8 8
1907	22 3 0	0.70	1 3	5 7
1908	16 2 6	0.60	1 5	7 0
1909	23 10 7	0.70	1 1	5 3
1910	27 18 7	0.81	1 2	5 6
1911	37 0 9	0.97	1 4	6 0
1912	27 2 2	0.74	1 0	5 1
1913	25 11 11	0.65	0 10	4 9
1914	18 18 4	0.49	0 7	3 7
1915	20 2 1	0.52	0 7	3 7

of this saving, but certainly not the major portion, is due to buying direct from the brush manufacturers instead of from the motor makers, this change having taken place in 1912.

#### CHOICE OF A MOTOR.

An effort has been made in recent years to adopt a standard motor, past experience having shown up a number of defects in various makes.

The principal points looked for are a liberal rating without undue weight and bulkiness, ease of dismantling, large bearings, and an accessible commutator. Suitable brush-gear is also a consideration. No brush-holder except of a positive radial type should be fitted to a motor. Old motors with obsolete brush-gear have been wonderfully improved by changing the holders.

Ball bearings should be avoided, for they are most unsatisfactory. Narrow pole gaps are also a great source of trouble. The small saving in efficiency is certainly outweighed by the greater risk of armature breakdown caused by a faulty bearing. Bearings inevitably wear; therefore such breakdowns are inseparable from motors with narrow air-gaps.

Needless to say, price is the least consideration when one has to be responsible for the upkeep of the motors. Hence cut prices and extra high speeds are avoided. On the other hand, very low-speed motors are unsuitable, on account of their size, for general hire work.

British motors are obtainable which fulfil most if not all of the above conditions.

#### CHOICE OF A STARTER.

It is unfortunately a fact that motor starters have not yet reached a very high state of perfection.

We were told that coils of wire must be avoided and cast metal grids substituted, but the metal grids break in handling the starter and are also condemned. Then we were told that self-contained non-corrodible carbon units were the most satisfactory; but these are found to give more trouble than their predecessors and are far more difficult to repair.

There are, however, some fairly good carbon-resistance starters on the market, and some of these look like developing on the right lines; but among starters that have been in use long enough for all their faults to develop, the author has not yet been able to find one which combines a good resistance element with sound switchgear.

Undoubtedly carbon with its negative temperature coefficient is the right material for starting a large motor. The largest motor on the author's mains is one of 250 h.p. which is started with a carbon resistance. This motor has a rope drive, and on the first contact takes 100 amperes. This current slowly increases and the motor begins to strain at the ropes until at about 160 amperes it slowly starts to move. Not only does such a start save unnecessary shock to the conductors of the motor, but it minimizes the disturbance to the supply. The question of drum versus lever-type starters for motors over 50 h.p. resolves itself into a question of design. Drum starters are unfortunately so cramped with blow-out coils, supplementary resistances, and various connections, that the author would prefer lever starters if it were not for the great difficulty in so making them that the handle can be relied on to fly back against the very considerable friction due to the pressure required to ensure contact for heavy currents.

#### STARTER BOARDS.

Where one has been able definitely to standardize starters and switchgear it is probable that the soundest job is to mount the starter, main switch, and fuses, on a standard iron frame, such standards covering a certain range of horse-power. But where, as at Hawick, the business has been gradually built up, and a great variety of starters are in use, sometimes with and sometimes without a shunt regulator, it has been found more convenient to mount them on a wooden board plugged flat on the wall and covered with asbestos-cement sheet. All wires are carried on the face of the board and fixed neatly with cleats. Any item of switchgear can thus be changed without difficulty in the shortest possible time, and one need never look for wiring troubles because all wires are in sight. Mains are also run on cleats, a short run of screwed tube only being used from the starter to the motor.

#### CHOICE OF A DRIVE.

The question of individual versus small or large group drives has been so often a subject of discussion before the Institution and elsewhere that it is not proposed to express any opinion on this matter. Suffice it to say that at Hawick small groups are the rule except in one or two tweed and spinning mills where large group drives have been installed on account of the saving in initial outlay. Individual drives for looms, etc., with continuous-current motors are of course out of the question. The author wherever possible prefers a belt drive to any other (except for heavy drives where ropes are preferable).

Owing to the peculiar local conditions, the variety of motors in use, and the large number of changes, it is far more convenient to drive by belt. In a very few cases chain, gear, or direct drives are in use, but the difficulty in making quick changes of motors is vastly greater than would be the case with belt drives.

Motors are preferably fixed on the floor, as they certainly receive more attention in this position. Occasionally there is no alternative but to mount them on brackets or hangers, or to hang them inverted from the ceiling.

For motors of moderate size it is usual to coach-screw them to battens, screwed or bolted to the floor. This again facilitates changing. When they are mounted on concrete foundations the usual plan is to sink a pair of battens in the concrete. If suitably placed apart a fairly large range of motors can be screwed down to them.

When power is required in damp places, such as dye-houses or milling houses, it is very necessary that the motor should be outside the actual house. In most cases it is possible to find an adjoining building into which the shaft can be extended, but occasionally a small brick lean-to has been built.

For large motors, say over 50 h.p., which cannot be

easily replaced at short notice, it is advisable to keep a spare armature and field coil. In the case of a large mill with a number of similar groups the author recommends the installation of duplicate motors as far as possible throughout, keeping one complete motor as a stand-by. This has been done in a fairly recent case, the motors of course not being hired but owned by the consumers.

In conclusion, the author, while admitting that there is very little that is in any way novel in this paper, trusts that it may be of interest to engineers wishing to obtain a larger power load by letting motors on hire. He also hopes that it may lead to an exchange of opinions and experience on a subject which has not received much attention by the Institution.

Acknowledgments are due to Mr. H. C. Babb, till recently Chief Assistant Engineer at Hawick, for valuable assistance in the preparation of the paper.

#### DISCUSSION BEFORE THE YORKSHIRE LOCAL SECTION, 8 MARCH, 1916.

Mr. Roles.

Mr. T. ROLES: I am particularly interested in this paper as the electricity-supply undertaking of the Bradford Corporation was, I believe, the first in this country to let electric motors on hire, a scheme for this purpose having been introduced in 1896 by Mr. A. H. Gibbings, then Borough Electrical Engineer. The hiring scheme in Bradford is therefore now in its twentieth year, and the prime cost of motors—both continuous and alternating—let out on hire at the present time is about £53,000. Up to the year 1907 only continuous-current motors were hired out, and machines of this type are still in the majority. The motors range in size from 300 h.p. down to  $\frac{1}{2}$  h.p., machines of  $4\frac{1}{2}$  to 5 h.p., which are largely used for cranes and hoists, being the most numerous. The hire rates which the author states are charged at Hawick are somewhat higher than those in force in Bradford, and I note that such rates have been increased considerably since the early days of the undertaking. I believe that our hire charges have never been increased since the scheme was inaugurated, nor have they been reduced, except for some of the larger motors, and I do not think that any general reduction is likely to be made in the near future, at any rate for motors up to 10 h.p. Consumers have not been encouraged to adopt the hire system for motors of over 30 or 40 h.p., as such machines are too bulky to be easily dealt with, and when for some reason or other a motor of such size is returned into stock there is a possibility of its remaining out of commission for some time, during which, although depreciating in value, it is bringing in no revenue. Our hire rates were, I believe, based originally on 10 per cent of the cost of the motors only, the charges covering the hire of the motor, slide rails, and starter—we do not supply switches or cut-outs. The charges were certainly low in view of the prices ruling in those days, but the idea was apparently to sell current for power purposes. The figure of 10 per cent is manifestly insufficient to cover repairs, maintenance, inspection, interest, and depreciation. If 15 years be taken as the life of a motor, a life which can now be safely assumed—as a matter of fact, there are some motors still on hire in Bradford which have been running for over 15 years—depreciation would equal nearly 7 per cent, and about 4 per cent

interest should be allowed on the outlay. Under these Mr. conditions the average amount to be set aside yearly for interest and depreciation would be nearly 9 per cent, leaving only about  $1\frac{1}{2}$  per cent to cover repairs, maintenance, and inspection, which is obviously insufficient for this purpose. I think that the annual charge should not be less than 15 per cent of the total cost of the motor, with slide rails and starter. I notice that at Hawick the rental covers the cost of all maintenance and renewals. At Bradford such is not the case—I believe we still charge for brushes. The cost of these to consumers is, however, now very small and is rarely objected to, but in the past it was often considerable. Again, any other damage than that due to fair wear and tear has to be paid for by the hirer. Probably at Hawick most of the machines are used for textile work, and consequently there is little risk of damage, but at Bradford the conditions are very different and I may mention as an instance a motor recently installed in an acid factory. Although we were assured that there were no acid fumes which would be likely to have a deleterious effect on the machine, it had only been in use a month or so before the windings had become completely ruined. I do not think that in cases of this description the undertaking should be at the expense of making the damage good. From the figures I have previously quoted it will be gathered that during the first few years the Bradford motor-hiring scheme was in operation there was little or nothing left for depreciation after the expenditure on repairs, maintenance, and inspection had been deducted from the income for hire. We had, therefore, to pursue the same course as that which I observe has been adopted at Hawick, and in 1906 a sum of over £7,000 was taken out of the general profits of the undertaking to cover depreciation on hired motors. Since that time we have yearly set aside a sum for depreciation purposes, and the hire department is now in a very satisfactory position; in fact, taking into consideration the extent to which the prices of electric motors have increased during the past two years, there is no doubt that we could at the present day dispose of our motors at a considerable profit on their present book value. Practically

the whole of the repairs to the motors are carried out at the works. With a large motor-hiring department it has been found very necessary to have a person in charge who will give a considerable amount of time and care to the work; and in that way the cost of maintenance, which might otherwise be very high, can be reduced to a very reasonable figure. In conclusion, I consider it to be very desirable that a hiring scheme should be in operation in connection with an electricity-supply undertaking. Such a scheme is often the means of enabling an undertaking to secure a new consumer, and it is undoubtedly an advantage to have motors in stock so as to be in a position to send one out at short notice in the event of a gas engine or a steam engine breaking down. Even if as the result of an occurrence of this description a permanent consumer is not immediately obtained, the power user's gratitude is earned, and he tells others of his experience and at a later date probably decides to adopt electric driving.

Mr. C. E. ALLSOPP: In connection with the Bradford hiring department, in March 1915 the number of continuous and alternating-current motors on circuit was 2,551, equivalent to 10,309 kw.; of these approximately 1,100 were on hire, representing 4,139 kw. The latest returns (February 1916) show 1,262 motors on hire, representing 7,337 kw., an increase of 162 motors or 3,198 kw. in less than 12 months. This increase, of course, is rather abnormal and is due to munition and other works mainly engaged on the production of war material. The stock of motors that we generally keep in Bradford is somewhat large. We have at the present time some 250 motors, varying from  $\frac{1}{2}$  h.p. to 100 h.p. in the case of continuous current and 1 h.p. to 300 h.p. for alternating current. Motors of less than 1 h.p. we do not consider should be dealt with to any great extent, because the amount of repairs necessary and their low efficiency do not recommend their use. As Mr. Roles has said, the hire charges are somewhat similar to those at Hawick, and we have found that no great opposition has been met upon this score because the rental forms a very small percentage of the consumer's total bill for electricity and hire. For instance, taking a 10-h.p. motor rented at £8 per annum and running at a load factor of 80 per cent during ordinary mill hours, the total charges, with electricity at 1d. per unit, would be in the neighbourhood of £80 per annum, the rental representing 10 per cent. If a consumer does not wish to pay the hire charges he has the option of buying the motor, and if he complains of the hire charges the motor is offered to him on favourable hire-purchase terms or direct sale. Our charges also provide for the temporary hire of motors and starters, and these charges are useful if a consumer's motor breaks down and he requires assistance for a week or so. In connection with hoisting motors above ground-level, if a consumer wishes to take the machine up in his own conveyance, such as a crane or hoist, he is at liberty to do so, but if he does not care to do this he is charged according to our table. The author has dealt briefly with the question of hire agreements; more information would be useful because an agreement covering all the various points that may come up in dispute is highly necessary. Each motor on hire at Bradford carries a numbered plate, such plate stating that the motor is the property of the Corporation, and also giving its weight, the last item being essential

to enable the motor fixer to choose his tackle for handling and fixing the machine. We find that a 6-hour test is more than sufficient, and in a good many cases the machines have reached their final temperature at the end of 4 hours. We have the usual method of testing, *i.e.* back to back for a load test, and the brake test with spring balance for ascertaining efficiencies. In order to overcome the difficulty of the various sizes of pulleys and shafts we have a set of testing pulleys, the diameters increasing in steps of half an inch with interchangeable bushes, the bores of which increase in eighths of an inch. It is highly necessary to have a very vigilant repair staff and the men should possess intimate knowledge of general motor windings and rewinding, and should have sufficient technical knowledge for minor calculations. Generally speaking, we find that coils can be easily made in our own shops at a very much lower cost than if purchased and to give equal satisfaction. Our experience has been that the number of breakdowns is in direct proportion to the number of men we take off inspection. In regard to reducing the mica on commutators, I should like to give a word of warning from our own experience that this must be carried out very cautiously; if effected too deeply, it will cause lodgment of carbon dust and dirt and result in short-circuits. The Bradford motor inspectors are provided with uniforms, the latter having a number on each collar. A systematic record is made to ensure the motors being inspected regularly, and the time, etc., is booked to each motor. Reports of trouble received at the works are entered up specially and receive attention from the superintendent in charge of the works, who deals with them specially or otherwise as he deems necessary. These occurrences are entered up separately and posted against the inspector on whose round the faulty motor is situated; and periodically these records are reviewed and, if necessary, the man is asked for an explanation of the great number of calls that have been received from consumers in his district. This procedure ensures that the inspector does his work to the best of his ability. With reference to starters, in Bradford we have an atmosphere that is more or less humid and full of acids, and we have found the sand-box type of starter with the resistance embedded in sand to give great satisfaction. We have endeavoured from time to time to standardize our starters and have succeeded in some instances in doing so. It is quite possible to standardize starters from 5 to 20 h.p. with interchangeable overload and no-volt coils. With reference to the use of ball-bearings and roller bearings on hired motors, we have every reason to be perfectly satisfied with our experience at Bradford with the numerous machines so fitted up to 150 h.p. Ball bearings were discussed in December 1912 in a lecture given by Professor Goodman before this Local Section, and our experience at Bradford fully bears out Professor Goodman's remarks. Ball bearings are satisfactory if treated and mounted correctly, the great fault with the early patterns being that the manufacturers did not realize that they were fitting them to a machine that had different characteristics from those which they had experienced previously, *viz.* that the heating first took place in the shaft from the armature and that the clearance adopted did not allow for the resultant expansion of the inner races. Greater clearances are now allowed, and if the bearings are properly mounted there is every reason to believe that they will give satisfaction. The

Mr. Allsopp: bearing manufacturers advocate that, up to 30 h.p., balls of the medium type should be used, and favor that ~~one~~ the short roller bearing with thrust washers on motors over 7 h.p. to take the end thrust that is experienced due to belt fasteners and other causes. In considering air-gaps of electric motors one has to take into consideration magnetic leakage and the usual rise of speed of continuous-current motors, and also what becomes a very vital matter in the case of alternating-current machines, viz. the efficiency and power factor. By adopting ball bearings the air-gap can be considerably reduced, with very good results. We have had considerable trouble with white-metal bearings and we have decided in many cases to change them for gunmetal bearings of a known mixture. One has to consider that the consumer is apt to run the belt of a hired motor too tightly and put undue stress and strain on the bearings, with the result that white-metal bearings soon run out. The cost of brush renewals at Bradford, for the number of motors already stated, is only in the neighbourhood of £16 a year. The mica is cut down on only a few machines which will not otherwise operate well, but I consider our low cost of brushes to be due to the use of the box type of brush-holder with brushes of extra bearing depth. My experience is that the radial brush is a thing of the past. We have 40 different sizes of brushes, and owing to our attempts at standardization, some of the brushes cover as many as 30 different sizes and makes of machines. A considerable amount of work was undertaken some years ago and a number of machines having badly designed brush-gear were taken in hand, the object being to increase the size of the brush and its wearing depth. In some cases it was possible to increase the length of  $\frac{3}{8}$  in. to 2 in. and to increase the useful bearing length from  $\frac{3}{8}$  in. to  $1\frac{1}{2}$  in. The total cost of this work on 274 machines including castings and machinery was only £127, and this amount has been recovered many times over since the work was completed.

Mr. R. H. CAMPTON: I think this paper shows what can be done in a small town with very few inhabitants and no tramway load. It is astonishing to notice how much human nature enters into so many points with regard to hiring schemes. What impressed me in the paper was the rapidity with which a fault on a motor is attended to. That a small place like Hawick can have two men on emergency calls shows that it is profitable to do so, although I should not have considered it to be a commercial proposition unless the men lived near the works. It also shows the esprit de corps which there is among the staff. I have always found in the case of motor-hiring departments that if one can train a carpenter he is the best man to have for this work. Other points to be borne in mind in connection with the letting on hire of motors are that it is not worth while hiring out motors for cranes and hoists, and that it is not of much use to cater for small loads unless one is thereby going to get other business. I was very interested in the question of ball bearings. I have not had much experience of ball bearings on motors, but have used them on other shafts and find the repairs to be very costly; one is also handicapped by not being able to fit balls in when one ball is worn, as the whole bearing has to be returned to the makers. Some 15 years ago we tried roller bearings on tramcars with very disastrous results, and since then I have hardly come across a roller bearing.

Mr. W. B. WOODHOUSE: The commercial side of the matter dealt with by the author appeals to me most. It appears that something like half the motors connected to the Hawick electric supply mains are let on hire. The author has regarded this business as a means of developing the supply, and the results justify his policy. The principle of making an inclusive charge for the various services rendered is sound; small additional charges are vexatious and produce little revenue. It would be interesting if the author would state in his reply the average period of hire. The hiring business deals with two broad classes of users, emergency work and continuous hiring, and it would be of value to know the proportion of each.

Mr. W. M. SELVEY: The remarks of a previous speaker Mr. are very different from the views expressed in the paper, and in each case the opinion is that of an engineer controlling a very successful business; but whilst one charges 20 per cent of the capital cost (giving, however, an overall service) the other charges only 10 per cent. The latter undertaking is about three times the size of the former, and probably this is the real explanation of the discrepancy. Looking for underlying tendencies, one is struck with the remarks to-night on the subject of inspection. The author has built up a business rapidly getting larger and the procedure in which is almost standard, and the load is altered not in kind but only in degree. Mr. Allsopp on the other hand has to deal with a much more complex load. It pays the author to wait until troubles occur, and it pays Mr. Allsopp to anticipate troubles. The author's way is truly British, but I think that Mr. Allsopp's method is the only possible one for the future. I should like to hear how the author settles the size of the motor to be installed, and how he guards against its being overloaded. I take it he has one meter per consumer and possibly an ammeter per motor, but this is very little protection against overload. Has he installed any device to show the maximum demand on a motor? I see he is continually changing a smaller motor for a larger one. In the early days of squirrel-cage motors where it was often left to the contractor to settle the size of motor, motors were put in so large that the average power factor came out incredibly low. This of course does not affect the author at present. On the other hand, motors are now often too small. This rating has been affected by general experience, and I believe in numerous cases the average load on a motor including overloads is under 60 per cent. This consideration equally applies to many small generators. The consequence is that if many types of plant were kept on full load for 8 or 10 hours and then made to do their rated 25 per cent overload for 2 hours, they would burn out or otherwise fail.

Mr. W. LANG: There is just one matter that has not been touched on to-night that I should like to refer to. I mean the difficulties which arise with the Electrical Contractors' Association whenever a Corporation takes up the letting on hire of motors or the carrying out of electrical work. I should like to hear the author's opinion on that subject, although he has probably had no trouble of that kind in Hawick.

Mr. E. BALMFORD: On page 565 the author says that consumers who possess their own motors are now usually advised to insure them with an insurance company whose rates are quite moderate. I should like to know if the

company with which he is connected insure their own motors, and, if not, what is the procedure in the case of a fire or other similar accident on a consumer's premises. That is to say, who is responsible for the motor?

Mr. H. H. WRIGHT: The first point I wish to refer to is that the rents charged by the hiring company appear to be exceedingly high. The rents charged by most of the municipalities in this district are very much lower than those charged by the hiring company, which represent something like three to four years' purchase. What strikes me is that, taking this fact into consideration, the profit made by the company is not larger. It may be due to the capital cost of the motors being rather high, or to the undertaking being a smaller one than some of the municipal undertakings referred to. The author mentions on page 564 the period of hire. It is more usual and, in my opinion, the better arrangement to make the minimum period of hire 12 months; one knows exactly where one is in that case and there is no possibility of any dispute. The last speaker anticipated a question I was going to ask, namely, insurance against fire. I think I am right in saying the Bradford Corporation insure their own motors, but that they charge the cost of the insurance against the hirer. I should like to know whether that is correct. On page 565 the author also mentions insurance against breakdown. In my opinion it does not pay to insure motors with an insurance company provided that they are reasonably looked after. The insurance rates for insuring motors against breakdown work out at something like 5 or 6 per cent on the capital cost, and I know of many cases where there have been absolutely no breakdowns for very long periods. The author does not mention how much depreciation he allows for, and I should like to know the amount. Also, I entirely agree with what Mr. Allsopp said in regard to white-metal bearings. Such bearings give one no warning. If a bearing gets hot due to want of oil or other reason, the white metal runs out practically instantly and the armature falls down on to the poles, resulting in damage to the binding wires or perhaps worse. Phosphor bronze on the other hand gives a certain amount of warning and time to renew the bearings. I think that at least 90 per cent of breakdowns are due to oil and dirt getting on to the windings. The author does not say how he treats his armature windings when he has repaired or wound the armature. Does he treat them by the vacuum impregnation process? I find this to be a good insurance against breakdown. Also, I am rather surprised that he does not inspect his motors in a more systematic manner. Possibly that is, as Mr. Selvey pointed out, due to the fact that the concern is perhaps just on the border line where such an inspection does not pay. If the business were to grow, no doubt inspection would have to be carried out. On the question of economizing in brushes, with high-speed motors I have always found it to be not good practice to recess the mica unless a hard quality of brush is used. Soft brushes are quickly worn away if the mica is recessed. With moderate-speed motors it is perhaps better to recess the mica. The author does not give us any idea what form of agreement he makes with the hirers. There is one point which is very important, namely, to insert a clause whereby, in

case of bankruptcy of the hirer, the landlord cannot dis-train upon the motor; such a clause should be inserted at the end of the agreement and the landlord's signature obtained.

Mr. W. E. BURNAND (*communicated*): Whilst not directly comparable with the author's, my experience being with alternating-current machines, in many particulars no doubt this will apply. The chief point of difference is that with the alternating-current motor, especially of the short-circuited rotor type, brush and commutator troubles and maintenance are avoided, which, especially in the case of small machines, will mean a considerable percentage saving in maintenance. The firm with which I am connected has practically no ordinary hire business, nearly all ours being hire purchase, the price to buy the motor at any time being reduced by the whole of the first quarter's rent and half of each subsequent quarter's rent, till finally the motor automatically becomes the hirer's property, the period for this being between 5 and 8 years according to the size of the motor. Examples of the rates charged are as follows, per quarter, payable in advance:—1 h.p., 10s.; 3 h.p., 25s.; 5 h.p., 33s. 6d.; 10 h.p., 48s.; 20 h.p., 75s. Considering that just over half of these amounts goes towards the purchase of the motor, it will be seen that the rates are substantially lower than those quoted by the author. I do not think, therefore, that this business would be of any use to contractors to hire at these rates, but as we are manufacturers and hire only locally, the business pays us quite well. The rates do not include fixing and connecting up as in the author's case, which probably accounts for part of the difference, the hirer in our case paying for wiring, main switch, and the cost of fixing the motor. For less than a year a higher rate is charged. The rates include maintenance, but do not cover breakdown due to accidental injury, although in practice we interpret this very liberally. At the same time when it happens, as has been the case in several instances, that damage to the motor has occurred owing to employees dropping turnings, twist drills, and bolts into the motor, the hirer has to pay for the cost of putting this right. We do a considerable number of repairs on continuous-current armatures as well as to our own alternating-current machines. For locating a short-circuited coil on an armature, we have fitted up a high-frequency machine delivering alternating current at 400 periods, and by means of this can get practically full voltage across the armature coils or the field magnets without running the motor. We have found this to be a very great improvement over the usual methods for locating faulty coils, which give much less than the working voltage across the coils. The saving in brushes and commutator wear mentioned by the author through undercutting the mica is particularly striking, and the fact that this saving is obtained rather points to the mica having been hard and the brushes somewhat soft, but there is no doubt that in most instances there is a very marked improvement by undercutting the mica. This cutting out of the mica should be done in the form of a V, since if the mica is removed with a hacksaw that fits between the commutator segments a space is left which is too readily bridged over by carbon dust, thereby possibly causing trouble owing to short-circuits. Regarding the third paragraph under the heading "The Choice of a Motor,"

Mr. Wright.

Mr. Burnand.

Mr.  
Bonand

I am surprised to note that ball bearings are condemned as most unsatisfactory; we adopted them after careful experiments for our hiring-out motors, as giving less trouble than oil-well bearings. With the latter we found that hirers were equally divided between those who oiled the motors every day and those who only oiled them when the bearings seized. Ball bearings with a good initial supply of grease and only a small grease lubricator got us out of this difficulty. The supply of grease in the housing is sufficient to run the motor for about two years without trouble, and by having only small grease cups the hirer can only get a very limited amount of grease into the bearing. The great thing with ball bearings is that everything must be in perfect alignment and perfectly true, and that no grit or dirt must get into the bearing. Provided that this be attended to, our experience is that such bearings are perfectly satisfactory. Regarding the trouble caused by wear of bearings, I think this is due mostly to faulty design or usage. With ball bearings mounted quite true, there is no appreciable wear in several years of use, and with oil-well bearings, if these are sufficiently long and properly lubricated, the wear hardly seems to be perceptible. For instance, we have had motors of the oil-well type run 9 years at 1,450 r.p.m. and on examination there has been no perceptible wear, the full length of the bearing not having been polished up. This shows that under proper conditions the shaft is actually floating on a film of oil, under which conditions the metallic wear should be exceedingly small. I am strongly in favour of a direct drive, as this does away with the space taken up by the main drive and saves two main pulleys as well as the belt, in addition to a certain amount of friction. It is very necessary that the men fixing these direct drives should be considerably above the average as regards ability and be carefully coached into getting absolutely perfect alignment, otherwise trouble is certain to follow. I am inclined to think that the floor is usually the worst position for a motor, certainly in the case of alternating-current motors, and wherever possible up to 20 h.p. such motors should be mounted on a wall out of the way. I do not think it is realized what a good foundation a reasonably sound wall makes, and provided that the motor be well balanced we seldom think of mounting anything less than 10 h.p. on the floor if there is a wall available, and in some cases even up to 20 h.p., with in every case favourable results. A motor thus mounted and connected with a direct-coupled shaft gives advantages in the way of efficient power transmission that cannot be obtained by any engine drive, and is worth the slight extra trouble, since a firm used to this class of drive will seldom take up an engine drive afterwards.

Mr Harmer

Mr. A. F. HARMER (*communicated*): The undertaking in which I am interested has run a motor hire department for about the same time (since 1903) as the author's. Of course, here (London) the proportion of factories, or users of motors, to the general population is not so great as in the North. It is interesting to note that whilst we have  $2\frac{1}{2}$  times the number of motors out on hire and hire purchase, the total horse-power is only nine-tenths of the author's, the average horse-power being  $3\frac{1}{2}$  approximately. The rates are very similar and, like the author's, have been raised from time to time. The average horse-power of the hire-purchase motors in the paper seems very large. In

Table 2 it is necessary to have so many different sizes? I should think that the  $2\frac{1}{2}$ ,  $3\frac{1}{2}$ ,  $4\frac{1}{2}$ , 6, 7, 9 and 18 h.p. sizes might be dispensed with. Our experience goes to show that one should be generous in the size of a motor applied to any machine and not reduce the horse-power too much if one wants to keep the maintenance down; hence very many sizes are not required. The most popular sizes here are 1, 2, 3, and 5 h.p. There is little call here for motors over 15 h.p.; nearly all cases can be arranged in small groups; moreover, anything over 15 h.p. is very costly stock to keep idle. The author's opinion on cut-outs for hire work would be of interest. Our experience is that any type requiring other than ordinary fuse-wire is an annoyance, causing delay owing to the special replacements not being to hand, etc.; moreover, the expense is greater. Starting switches cannot be prevented from sticking over from time to time, and hirers do by no means always see that the handle is put back before closing the main switch again. I agree with the author that practically all repairs and replacements should be free. I should like to know the author's average cost of installing a motor, including delivery and return. A large business is done here in what one might call temporary hire, that is, for builders' hoists, mortar-pans, etc., on a monthly basis. In testing, I notice the author uses a dynamo with, presumably, a tub or resistance as load; we gave this up some years back in favour of the Walker fan dynamometer. We have the 6-h.p. and the 60-h.p. sizes, so that any horse-power between  $\frac{1}{4}$  and 60 can be tested. These are extremely convenient and quick to rig up, and can of course be left running for as long as required without any of the variations one gets with tubs, etc. Admittedly they are rather dangerous and should only be fitted and used by a very careful operator, and, if left running, the motor under test should be in a place inaccessible to unauthorized persons. I do not agree with the author in the use of gib-head keys for pulleys; not only is there a tendency for a man to drive these in unremovably tight, but the projecting head is a source of danger when the motor is running. I find nothing better, in all ways, than a feather fitted in a blind slot in the shaft and held down with a grub or set-screw. I agree with the author in keeping as much as possible to one type of motor; this enables one to keep spare armatures, etc., without a great and varied stock. The author seems to be able to change motors in an exceedingly short space of time; I presume the time given is after the spare motor is on the spot. I see that he is troubled with starters and does not think much of them in general; I heartily agree with him. Regarding inspection, I find that the neglect of this at frequent intervals causes an enormous amount of trouble. Quite a number of hirers allow brushes to wear down and spark, without taking any notice of it until the motor shuts down; also too much oil or none at all is constantly occurring. Very few hirers take pride in keeping the motor in the cleanly state the author mentions, particularly in the more domestic trades. We had no projecting mica until about 1910, and then only with a certain type of motor of a certain make. The mica of any motor of this type is always cut out as the opportunity occurs. As a general practice on other types we do not consider it to be necessary. I should like to know the author's method of recessing; we use a narrow parting tool in the slide worked along the lathe-bed by

hand; it seems a very slow process, a 10-h.p. armature taking about 3 to 4 hours, including turning up. Complaints occur from hirers regarding the singing noise the motor makes after recessing. Has the author had any trouble from short-circuited segments due to carbon or other dust lodging in the recess? I agree with him regarding the price and speed of motors, and I find the most suitable speed to be 1,000 to 1,200 r.p.m. up to 5 h.p., and 700 to 800 r.p.m. for the larger sizes.

Mr. H. JOSEPH (*in reply*): I am very much interested in Mr. Roles' description of the methods adopted at Bradford. Their charges as I understand are considerably lower than ours for the smallest sizes of motors, but rather higher for the larger ones. On the average they are appreciably lower, but they do not undertake as much as we do. We practically insure the drive. Our power consumers at Hawick are busy producing woollen fabrics and prefer to hand over their electric drive to the supply authority rather than be troubled with it at all. We do not consider it to be good policy to quibble about possible misuse. If consumers neglect their motors their mills may be stopped for an hour or two. We get them to appoint a man in each department to look after its motor or motors. I think Mr. Roles would do better to provide the whole equipment and be responsible for all maintenance, charging a little more for hire. It seems curious to charge for such a small item as brushes.

Mr. Allsopp's remarks are particularly interesting, and I think that some of the particulars in which the Bradford system differs from ours are mostly due to the difference in the relative sizes of the undertakings. I cannot help thinking, however, that his elaborate scale of charges for hoisting are rather unnecessary. Our terms for temporary hire are the same as for longer periods, but the hirer pays all costs for installation and removal. Mr. Allsopp rightly asks if full provision is made in the motor-hire agreement for all probable contingencies. I think this agreement is quite adequate. It was drawn up with the assistance of the best legal advice and contains a clause under which the hirer undertakes to include the motor in his fire policy. There is also a clause safeguarding the supply company against distraint in the event of bankruptcy. I note that the Bradford Corporation use numbered plates on which the weight of the motor is stated. I consider this to be an excellent plan. We of course fix a plate indicating that the motor is the property of the supply company, and we propose to paint on each motor particulars of its weight. It is certainly very useful to have this information to facilitate the selection of the proper tackle. If our motor-hire business were on the scale of that at Bradford we should certainly wind our own coils, but I have carefully considered this point and have come to the conclusion that, for the comparatively small number of rewinds with which we have to deal, the initial outlay and the large and varied stocks of wire required would not be justified. Mr. Allsopp, and one or two other speakers, seem to think inspection essential to success. I can only repeat that we have tried it at Hawick and found that it does not pay to inspect all motors periodically. That this is not the case in a large district with various classes of trades is quite probable. Inspection at Hawick is largely rendered unnecessary because we have got our consumers into the way of letting

us know at once if a motor begins to spark badly or otherwise to behave in an abnormal manner. We also get the men in charge into the habit of spending a short time once a week cleaning the machines and examining the brushes. Some of the smaller users, however, cannot be relied on to give much attention to their motors, and we therefore keep a more careful watch on these motors ourselves. It would be interesting to know what it costs the Bradford Corporation merely to inspect their motors apart from repairs.

A good deal has been said by various speakers on the subject of ball bearings. It would be idle to deny the advantages of this kind of bearing from many points of view. But from the aspect of the maintainer they have one great disadvantage, namely, the difficulty in removing the armature when a quick repair is necessary. One can only judge by one's own experience, and we have usually had considerable difficulty in withdrawing the ball races. We have also found them very liable to wear, broken balls and scored races being by no means uncommon. Probably a good gunmetal bearing is preferable to white-metal, but the former if it does seize is difficult to get off the shaft, and may even have to be split before it can be removed.

Mr. Allsopp's condemnation of radial brush-gear is clearly a confusion of terms, since he praises the box type which is the type referred to in the paper under the heading "Choice of a Motor." He evidently means radial with respect to the brush spindle, while I mean radial with regard to the armature shaft. I was astonished to hear the low cost of brushes at Bradford. I understand that it is due largely to using brushes which are as long as possible, since the length wasted is a large proportion of the whole. This is a point that needs investigation. At Hawick we have also fitted new brush-gear to a number of motors with very considerable success.

I have to thank Mr. Campion for his remarks. The way we are able to have men available for emergency calls is indicated in the paper, namely, by having all outside men trained for motor work. In case of a motor breakdown they are taken away from other jobs if necessary, and can usually be called in by telephone.

I am glad to note that an engineer of Mr. Woodhouse's standing and experience agrees with what I regard as one of the most important points in our system, namely, to ignore all possible extra charges and to make the motor rental cover all contingencies. This policy was adopted by my predecessor, Mr. Rye, under whose auspices the hire system was inaugurated, and I have continued on the same lines in this respect, being convinced that it is good business. Regarding the average period of hire, a motor usually continues to be hired until it is replaced by a larger one. In hosiery mills it pays the hirer better to add to existing groups than to pay for the hire of two motors. At a rough estimate a motor probably remains on one drive for an average of five years, after which it comes back into stock and is overhauled. It is not long as a rule before it is out on hire again. The bulk of the motors are on what Mr. Woodhouse refers to as continuous hiring. Emergency drives average three to six months. The cost of such motors, as well as the rentals received from them, are excluded from the tables in the paper. They form a very small proportion of the total.

Mr. Joseph.

Mr. Selvey mentions, I think, the radical cause of some of the differences of procedure at Bradford and Hawick. Later on he asks how we settle the size of the motor to be installed and how we safeguard its immunity from overload. For normal drives we know by experience the horse-power required for a given machine or group of machines. When we are called on to drive a new class of machinery we can only guess at the power required, and install a motor of which the size is on the liberal side. Owing to our system of fixing, a motor can be easily changed if on test it is found to be too large or too small. For motors of 20 h.p. and over, an ammeter is permanently fixed. For smaller ones a standard cut-out is used, for which we have made an ammeter shunt that is interchangeable with the porcelain-bridge fuse. By temporarily short-circuiting the cut-out, the shunt can be inserted and withdrawn without stopping the motor. We have got consumers into the way of informing us when they add extra machinery, in order to enable us to take a test.

In reply to Mr. Lang's question *re* contractors, I would inform him that owing largely to the geographical position of Hawick, situated as it is 50 miles from any town of considerable size, we do not come in contact to any extent with contractors. When this has occurred we have always experienced courteous treatment, and manufacturers do not attempt to induce consumers to purchase their machines direct and discard their hired motors. We are allied to a powerful company and it would be an unwise policy for any manufacturer to attempt to do so.

Mr. Balmford asks about insurance. Consumers owning motors are advised to insure them against breakdown. Hirers must insure them only against fire. Our agreement expressly makes the hirer responsible.

Mr. Wright expresses surprise that with the comparatively high rentals charged the profit is not higher. This, as pointed out in the paper, is largely due to the high cost and low rentals of motors during the first few years. This state of affairs is continually improving. We have not found any difference in the behaviour of high-speed and low-speed machines as regards recessing mica. Most of the brushes in use on motors at Hawick are on the hard side.

Mr. Burnand's hire-purchase system is very interesting, but it is difficult to see how it can be profitable to him. The maintenance costs of about 6 per cent at Hawick are, we consider, fairly moderate, and unless Mr. Burnand is much more successful than we are, one would imagine that he would hardly clear 5 per cent on his capital outlay. If such favourable terms are necessary to procure a good motor load no doubt they are justified, but as we have succeeded in selling nearly 3 million units last year at Hawick with a population of under 17,000 largely owing to our motor load, it does not appear that in our town at any rate the hire charges are such as to militate against a

good motor load. One wonders whether Mr. Burnand would not be at least as successful if he raised his rates by 50 per cent and let his consumers drop twist drills into his motors with impunity. I am afraid I do not agree with him that mica should be cut in a V shape. Our experience has certainly been that where this is done the radial flakes of mica lying against the sides of the commutator bar very soon have a tendency to rise again and interfere with sparkless commutation. I think that if the depth of cut is restricted to say 1/32 in. or thereabouts, there is no danger of carbon dust accumulating. While admitting that from the point of view of economy in space, as well as of saving in power, a direct drive is preferable to belting, the peculiar local conditions at Hawick referred to in the paper practically preclude the former method for such general work as is dealt with in the paper. We prefer to place motors on the floor where possible because they receive more attention in this position. If a man has to get a ladder to attend to a motor it is liable not to receive the periodic inspection and cleaning which we have got most users in our district to give the motors they hire.

I am glad to find that Mr. Harmer's hire rates are similar to ours. The reason so many odd sizes of motors are scheduled is because some of these sizes such as 2½, 3½, and 4½ h.p. are standard outputs of certain makes of motors at the Hawick voltage, and a considerable number of such sizes were in use before the scale of charges was standardized. Nearly all the motors on hire purchase are in use in one large mill where very large groups were considered to be necessary. The hire-purchase system is not a standard arrangement and is not being continued, but it was peculiar to this mill and I think to one other small consumer. These figures were isolated in order to prevent the other two sets from showing a false average. I am glad Mr. Harmer mentions cut-outs, because our experience in this matter may be of some interest. After a long series of troubles with porcelain-bridge cut-outs blowing to pieces on a dead short-circuit, we have adopted during the last few years the simple device of drawing a copper fuse-wire through a piece of woven asbestos tubing. This so successfully damps the arc that fuses may be blown on a dead short-circuit without any injury to the cut-outs. The average cost of installing and removing a motor of say 6 h.p. at Hawick is about £2 to £2 10s. The method of testing in use is to take current from the supply mains for running the motor and return it to the system from the dynamo, which is fitted with a field rheostat. The time given in the paper for changing a motor includes taking the spare motor from stock. This is usually done on a motor lorry and does not waste any time, for it is generally available for fixing by the time the other one is removed from its bed. Mica is cut with an old hack-saw blade suitably mounted, or a piece of "comb" such as is used in the local spinning mills.

#### WESTERN LOCAL SECTION, 3 APRIL, 1916.

Mr. H. F. PROCTOR: I notice from Table 4 that the cost of maintenance has increased from 0·2 per cent of the capital cost in 1903 to 6·2 per cent in 1915, and that the author believes it has now practically found its level. I think, however, it would be very interesting, and most

instructive, if he could give figures splitting up the cost of maintenance; I believe that it will be found to vary according to the sizes of the motors, and I should like to know if he could give it in pounds, shillings, and pence, or on the basis of percentage of the capital cost for different

sizes of motors. I think the cost of maintenance of large motors would prove to be less, in proportion, than that of small machines, and that much of the cost would be made up of small items. It would depend on the class of parts supplied and the number of breakdowns, rather than upon the size of the plant affected. I myself do not feel competent to discuss this matter, as, although we have a number of motors on hire in Bristol, we do not maintain them, we put the cost of maintenance on the consumer. The author mentions having written down the capital cost at different times. I think it would increase the value of the table in question if he could give us the original cost, instead of the written-down cost. For example, in the year 1912 the capital cost appears to be less than in the year 1911, which apparently indicates that he has written down in that year. I notice one very interesting point, namely, that the author says he never disputes liability in the event of a breakdown. This was one point that we considered very carefully when we were contemplating the hiring of motors in Bristol. We were afraid that if we undertook the maintenance of the motors it might lead to carelessness on the part of the customers, or rather of their employees. I should like to ask the author whether he has always undertaken the maintenance, or whether it has been subsequent to the operation of a simple hire arrangement; and if the latter, whether the motors are as well cared for by the customers since they were relieved of the cost of maintenance. In Bristol, we let motors out on simple hire only, but a customer may take over the machine at an agreed depreciation at any time he pleases. We have often found that a man will hire a motor in the first instance, and directly he has proved that the equipment is to his satisfaction, he buys it.

Mr. E. G. OKELL: I should like to know whether the author places any limit to the size of motors offered for hire, and also, following Mr. Proctor's request for the classification of the cost of maintenance of different sizes, to know the character of the maintenance that is most expensive. In regard to repairs to field coils, I should like the author to explain why it is considered advisable to avoid soldered connections if possible.

Mr. P. F. CRINKS: I should like to hear other opinions on the question of motors for damp places. The author says it is very necessary to put the motor outside the actual house, and he recommends putting it in an adjoining building and extending the shaft. I should like to know his reason for this. I think I should be inclined to install a totally enclosed or pipe-ventilated motor, as by the other arrangement the losses are bound to be very heavy. It seems to me that motors of this class would make a more satisfactory, and probably a cheaper arrangement, but I should like to know what the author's experience has been.

Mr. A. C. McWHIRTER: Regarding the equipment of the author's workshop the details of which he has given so minutely, I do not see any mention of a drying stove for drying out the machines, etc., a part of the equipment which I consider to be very essential. It would be interesting to know how many contractors there are in Hawick, as according to the paper the supply company leave very little opportunity for competition. In connection with short-circuited coils and armature faults, the

author states that a coil can be cut out when the armature is lap wound. Why cannot it be done when the armature is wave wound? In regard to the painting of motors after overhaul, the colour scheme seems very elaborate; I think it would be much simpler to paint the date, say, inside the machine or other convenient place. I entirely disagree with the author as to soldered connections of field coils; we do a great deal of soldering and never get any trouble unless it is due to careless workmanship. It would be a very costly affair if, say, the wire broke (while winding) when a field coil was almost completed and had to be scrapped because joints were prohibited. I can sympathize with the author regarding the annoyance caused after an armature has been rewound with old coils, to find that it breaks down immediately on being put to work or on test. We find in small armatures up to 10 h.p. that it is almost as cheap to rewind with new material; the completed job is infinitely more satisfactory to the repairer and more reliable to his client. I cannot agree with the author's statement that ball bearings should be avoided. To my mind, when properly installed and of ample size they form an ideal arrangement for either direct or belted drives, but I would not use them with pinion drives, the best arrangement for the latter being a ball or roller bearing at the commutator end and a solid bearing at the pinion end. Some makers put this type of motor on the market. I am much in favour of systematic inspection as the best means of preventing breakdowns, more especially where no skilled labour is employed to look after the motors. Such inspection as the various insurance companies undertake is to be recommended, the cost of the same being very low.

Professor D. ROBERTSON: The author refers to trouble from fracture at the leads to the hold-on coils in motor starters. I have had similar trouble in other small apparatus, and in some cases I have been definitely able to trace it to the use of soldering pastes "absolutely guaranteed not to corrode" the wires. For all small work, at least, nothing but resin should be permitted as a soldering flux. I can sympathize with the author in his complaint about the design of starters. Some years ago I had occasion to purchase a very special starter-regulator requiring an unusually great resistance. Although it was made by a firm of the very best repute and cost almost as much as the motor itself, we found when it arrived that the iron strapping used for the frame was so weak that it had yielded during transport and that the rheostat was consequently full of short-circuits. Quite recently another machine was wrecked under circumstances in which it would probably have been saved if the starter lever had not failed to fly back. In my opinion, in all except the smallest starters the lever ought not to be held directly by the magnet, but by means of a trigger, so that much more powerful springs can be employed. There is also much room for improvement in the details of the pivot and spring. The author's mode of fixing the starter on a wooden batten does not seem to me to be quite safe. Some time ago I almost had a fire caused by a starter fixed in that way, which I had previously considered safe. Of course, with an ordinary fly-back starter there seems little likelihood of its being overheated for a sufficient length of time to get a dangerous temperature at the wood, but one

Mr.  
McWhirter

Professor  
Robertson

Professor  
Robertson

must remember that probably the majority of fires are started in ways thought to be impossible. It would be better to space out the starter a few inches in front of the asbestos sheet.

Mr. Joseph

Mr. H. JOSEPH *in reply*: I regret that I have no figures for the cost of maintenance of different sizes of motors, and I agree with Mr. Proctor that such figures would have been very interesting if available. The arrangement we have adopted is to keep the cost of labour and material for motor repairs in a "Motor Repairs Account," and not in a separate account of the repairs to each different motor or size of motor. While the latter account would be very interesting, the labour and clerical work involved would be out of all proportion to the value of the record. We are satisfied on the point that the smaller motors cost more to repair, in proportion, than the larger ones for the reasons indicated in the paper. Regarding the suggestion that the costs are not original costs, to a certain extent what Mr. Proctor says is correct, but the system we work on is this. Upon reference to Table 3 it will be observed that in the year 1915 we added seven motors; it does not necessarily follow that this is the actual number of motors installed during this year, in fact it was 10, but 12 were disconnected; the figure represents the difference between the motors put in, and those taken out or transferred to another place. Sometimes a customer requires a motor taken out and a larger machine installed; in that case the motor is taken into stock, and cleaned, until it is required for some other drive, when it goes out again at a written-down price. In this way we have motors going out at much lower rates than they were originally bought for, and the net increase in capital costs may be very low or even a negative quantity. I am interested to note that Bristol does not maintain any motors.

In regard to the question of liability in the event of a breakdown, we never dispute this, although we know there is a certain amount of risk that a man may treat the motor badly, but we are prepared to take this risk, in the same way as insurance companies have to take risks. The consumer looks upon it as a sort of insurance, and of course the risk is really allowed for in our hire charges. I understand that the hire rates at Bristol are about half those at Hawick. I admit that we charge high rates at Hawick, but of course we endeavour to earn a dividend for our shareholders, whereas with a Corporation I believe the idea is first of all to satisfy the customer. We have always undertaken the maintenance, but more than half the motors in Hawick are owned by consumers, and we are therefore able to judge as to what attention hired motors receive as compared with the former. Our experience is that there is very little difference in this respect, at any rate as regards the larger users. We endeavour to get the owner to appoint one man to look after the motor in a particular department, and to make that man responsible for it. Our idea is that the man knows that if the motor breaks down, the mill, or a section of the mill, will be stopped, and his desire to prevent such an occurrence is usually sufficient inducement to make him endeavour to prevent a breakdown occurring from neglect or carelessness.

In reply to Mr. Okell the maximum size of motors let on hire is 50 horse-power. I regret I cannot give him

any figures showing what items of repairs cost the most. For 1915, deducting brushes, labour represents about half the cost of maintenance.

Regarding Mr. Okell's and Mr. McWhirter's remarks about soldered field connections, I am interested to note what their experience has been on the subject, but while I am prepared to agree that it would be much easier to make a soldered joint if such were satisfactory, I have always been given to understand that they should be avoided. If Mr. McWhirter as a manufacturer has found soldered joints satisfactory, he is in a much better position to judge than I am.

Mr. Crinks raises the question of motors for damp places. I do not know whether he is aware of the sort of places that one sometimes has to put motors into, and the class of machinery they have to drive in an industry like that at Hawick, but I would mention that in a Scotch milling house the atmosphere contains a large amount of steam and moisture, and sometimes also acid, which would be destructive of anything that could be used in the construction of a motor. In these circumstances, and as we do not wish to supply special motors for special jobs, we prefer to install an ordinary motor outside the house and to extend the motor shaft through the wall, since we feel it is better to do this than to supply a totally enclosed motor, and even then run the risk of the motor getting corroded.

Mr. McWhirter asks if we use a drying stove. We do not, but the building is steam heated, and a fairly high local temperature can be obtained when necessary for drying purposes. There are no wiring contractors at Hawick, and as we are some 50 miles from Carlisle and Edinburgh—the two nearest large towns—we are not troubled by manufacturers wanting to advise a consumer. Our motors have been bought from a number of different makers, who no doubt are satisfied to receive orders from us rather than to deal with the customers direct. The objection to short-circuiting a coil in a wave-wound armature is the difficulty in an emergency of finding the two ends of the coil. It is of course quite possible to short-circuit the coil with a piece of wire, but it is an operation that we prefer to carry out in the shop if possible. We do not give our men a list of colours, and it is not our intention to adopt an elaborate colour scheme, but the idea of the different colours is to give a rough guide as to how long a motor has been running, *i.e.* whether it has been running for some time or has only recently been done up. I agree with what Mr. McWhirter says about the danger of undercutting the mica to too great an extent. Of course, if a motor has been running very well, we should not cut the mica at all; but we have certainly found in a large number of cases of machines described by the customer as bad motors, that there was nothing really amiss beyond the mica being rather high, and when this had been recessed the motor ran excellently. I agree that the mica should not be cut too deep;  $1/32$  in. is ample.

I am afraid my remarks about ball-bearings have been somewhat misunderstood. I did not mean to suggest that ball bearings were unsatisfactory; our objection to them is purely a local one, due to the length of time required for effecting a repair. For instance, it would probably take about three hours to take out the armature of a

30-h.p. motor, as we should have to take off the end shields, which would be a lengthy process. We have some motors in use with ball bearings, and the proportion of troubles has been quite as great as with the other type; we feel that the time and labour required to remove the end shields of a motor with ball bearings outweigh any advantage which may be obtained from their use, especially as we have sometimes found it necessary to send for a new bearing.

In regard to inspection, about four years ago I determined to have all the motors inspected, as I thought this was the proper thing to do. Our experience, however, proved most unfortunate, as we often found that probably a fortnight after a man had called a motor broke down, although the machine appeared to have been running satisfactorily when he inspected it. We are now getting the consumer to let us know when anything appears to be amiss. We estimate that a monthly inspection of all hired motors would increase our maintenance costs by nearly 50 per cent.

Professor Robertson's remarks on the question of starters are very interesting. We use a preparation which has been adopted extensively and is known as asbestos cement. It is a very hard and tough material, and is an excellent

insulator for covering starter boards. This asbestos cement is about 3/16 in. thick. Of course, we do not issue any starters which do not include hold-over coils. I was interested in Professor Robertson's remarks about the framework of starters frequently being too light. I have experienced similar troubles myself, and I believe it is now becoming quite a standard practice in most towns where this business is carried on to have iron fixing boards drilled with standard holes. I consider this to be an excellent arrangement, but I do not think it could be adopted in a town like Hawick, until there is some form of recognized standard starter; at present there are all sorts and sizes of starters. For a flexible arrangement I do not see any real objection to our arrangement of mounting them on a wooden board plugged flat on the wall and covered with asbestos cement, and this arrangement also looks satisfactory. I do not think there will be many cases of trouble such as Professor Robertson mentions. He also asks whether maintenance charges include all the labour, and whether a man's time is charged to the job when he is called away temporarily from some other work to assist. We keep one man who spends nearly all his time on motor repairs, and when other men are called off other jobs to assist, their time is properly allocated.

## INSTITUTION NOTES.

PROMOTIONS, TRANSFERS, ETC., OF MEMBERS  
ON MILITARY SERVICE.

## (THIRD LIST.)\*

## MEMBERS.

<i>Name.</i>	<i>Corps, etc.</i>	<i>Rank.</i>
Caldwell, J.	Argyll and Sutherland Highlanders	Captain
Capper, D. S.	Royal Warwickshire Regt.	Major
Carter, W. L.	Royal Engineers	Captain
Haslam, S. B.	Welsh Regt.	Captain
Marshall, W. H. U.	Dorset (Fortress) R.E.	Lieutenant
Raphael, F. C.	London Electrical Engineers, R.E.	2nd Lieut.

## ASSOCIATE MEMBERS.

Anido, A. J.	London Electrical Engineers, R.E.	2nd Lieut.
Beer, R. G.	Royal Engineers	Lieutenant
Bellamy, L. C. F.	Royal Engineers	2nd Lieut.
Benson, H. K.	Glamorgan (Fortress) R.E.	Captain
Bland, M. G.	London Electrical Engineers, R.E.	Captain
Brearley, C. A.	Divisional Engineers, R.N.D.	2nd Corpl.
Buckton, W. W.	Royal Engineers	Captain
Bumpus, B. E.	Northumberland Fusiliers	2nd Lieut.
Cater, F. L.	Air Service Corps	2nd Lieut.

\* See pages 507 and 494.

## ASSOCIATE MEMBERS—continued.

<i>Name.</i>	<i>Corps, etc.</i>	<i>Rank.</i>
Church, H.	Essex (Fortress) R.E.	Sergeant
Davies, L. H.	Royal Garrison Artillery	2nd Lieut.
Dinham-Peren, A. E. H.	Royal Engineers	Lieutenant
Ellis, M. I. W.	Cheshire Brigade, R.F.A.	Captain
Ellis, T.	Argyll and Sutherland Highlanders	Captain
Empson, A. W.	Motor Machine Gun Service	Sergeant
Ewer, G. G.	Essex Regt.	Major
Gibson, J. S.	Royal Sussex Regt.	2nd Lieut.
Goulden, C. H.	Royal Garrison Artillery	Lieutenant
Grace, C. B.	Kent (Fortress) R.E.	Major
Hayward, C. H.	Royal Naval Air Service	Flight Sub-Lieut.
Jones, J. G.	Royal Fusiliers	Lieutenant
Lefroy, H. P. T.	Royal Engineers	Major
Lewis, W. R.	Royal Flying Corps	2nd Lieut.
Manners-Smith, I. A.	Royal Garrison Artillery	Lieutenant
Martin, L. C.	East Anglian R.G.A.	2nd Lieut.
Masters, F. H.	London Electrical Engineers, R.E.	Major
Matravers, F. G.	Royal Navy	Eng. Lieut.
Nelson, G. D.	Royal Naval Air Service	Lieutenant
Owen, L.	Provisional Battalion	Sergeant
Palmer, J. H.	Royal Fusiliers	Lieutenant
Payne, F. G.	Lincolnshire Regt.	Captain
Powell, C.	Lowland Divisional R.E.	Lieutenant

ASSOCIATE MEMBERS. *continued.*

<i>Name.</i>	<i>Corps, &amp;c.</i>	<i>Rank.</i>
Payne, F. D.	Royal Engineers	Captain
Reed, H. K.	London Electrical Engineers, R.E.	2nd Lieut.
Riley, T. N.	Divisional Engineers, R.N.D.	Lieutenant
Rutherford, J. A.	Machine Gun Corps	Captain
Salt, C. W.	London Electrical Engineers, R.E.	2nd Lieut.
Smith, T. A.	Royal Engineers	2nd Lieut.
Taylor, G. S.	Northumberland Fusiliers	Captain
Tyler, H. W.	Kent (Fortress) R.E.	Major
Unwin, F. R.	London Divisional R.E.	Captain
Watts, H. W.	East Surrey Regt.	Lieut.-Col.
Whittington, R. H.	Royal Fusiliers	Captain
Williamson, G. W.	Royal Flying Corps	Captain
Wood, A. E. G.	Divisional Engineers, R.N.D.	2nd Corpl.

## ASSOCIATES.

Cunningham, T. C.	Royal Garrison Artillery	Major
Madge, R. G.	London Electrical Engineers, R.E.	Captain
Norman, Sir H., Bart.	Ministry of Munitions	Captain
Simpson, L. S.	Royal Engineers	Major
Tucker, W. S.	General List	2nd Lieut.

## GRADUATES.

Browne, W. S.	London Electrical Engineers, R.E.	2nd Corpl.
Burnett, F. E.	East Riding (Fortress) R.E.	Lieutenant
Campbell, Sir J. A. C., Bart.	Scottish Horse	Captain
Curling, H. W.	Army Service Corps	Captain
Sheppard, J. H. D.	Army Ordnance Dept.	Captain
Vandermin, C.	Royal Fusiliers	2nd Lieut.

## STUDENTS.

Albrecht, E. C.	Royal Engineers	Sergeant
Anderson, S. G.	Royal Engineers	Lieutenant
Bedford, J. T.	Royal Monmouth R.E.	2nd Corpl.
Berry, T. B.	Royal Engineers	Lieutenant
Barton, R. G.	London Electrical Engineers, R.E.	2nd Lieut.
Campbell, S. A. B.	Hussars	Trooper
Cuerdon, H. S.	Army Service Corps	2nd Lieut.
Dawson, G. G.	Royal Naval Air Service	Flight Lieut.
de Cordova, M. R.	Army Service Corps	Captain
Denison, H. A.	King's Royal Rifle Corps	Lieutenant
Dixon, F. C. W.	Oxford and Bucks Light Infantry	Lieutenant
Elliott, J. W.	Royal Engineers	Sergt.-Major
Fruhe-Sutcliffe, R.	Provisional Field Co., R.E.	Captain
Gibson, J. A.	Royal Flying Corps	2nd Lieut.
Jenkins, A. M.	London Electrical Engineers, R.E.	2nd Lieut.
Lovell, W. H.	Grenadier Guards	2nd Lieut.
Macklin, R. W.	Royal Garrison Artillery	Lieutenant
Philipp, R. C.	Royal Engineers	2nd Lieut.
Rawson, S. M.	Royal Fusiliers	2nd Lieut.
Snell, J. B.	Royal Engineers	Lieutenant
Trutch, C. J. H.	Royal Naval Air Service	Sub-Lieut.
Voss, H. A.	London Electrical Engineers, R.E.	2nd Lieut.
Wiley, J. R. A.	Northamptonshire Regt.	Lance-Corpl.

## ENEMY MEMBERS.

At the Informal Meeting of Corporate Members held on the 8th March, 1916, it was decided to invite the Corporate Members to express, by means of reply-cards, their approval or disapproval of each of the four proposals adopted by the meeting, which are set out below. The replies received have been examined by two scrutineers (Messrs. C. A. Baker and F. B. O. Hawes), who have reported that the result is as follows:—

Number of cards issued: 3,244

Number of cards returned: 1,470

<i>Proposal.</i>	<i>In favour of the proposal.</i>	<i>Against the proposal.</i>
(a) To expel members who are subjects of enemy Countries or States ...	1,320	88
(b) To expel members who being naturalized British subjects have retained enemy nationality ...	1,307	79
(c) <u>Not</u> to expel members who are naturalized British subjects and were formerly subjects of a Country or State now at war with Great Britain and Ireland but who have under the laws of such Country or State definitely lost their alien nationality, provided they are able to prove this to the complete satisfaction of the Council ...	1,081	264
(d) That no person shall after the..... day of.....19....., be eligible for election as a member of the Institution who is a subject of any Country or State with which the United Kingdom of Great Britain and Ireland is or shall have been at war on or after the date mentioned... ..	1,120	200

A Resolution has been drafted to carry out the objects proposed, and has been submitted to two Counsel. The opinion of one Counsel has been received, and as soon as the second is available, the necessary meetings of Corporate Members will be called.

## RUSSIAN TRANSFORMER OILS.

The Insulating Oils Sub-Committee of the Research Committee have so far been unable to obtain supplies of Russian white transformer oils for the purposes of the research on transformer oils. The Sub-Committee would be glad to receive, through the Secretary, suggestions as to sources from which supplies of Russian oils which have not yet been in service could be obtained. About 40 gallons of each brand would be required.

## THE INSTITUTE OF METALS.

Members are invited to a meeting of the Institute of Metals to be held in the Lecture Theatre of the Institution on the 4th May, 1916, at 8.30 p.m., when Professor W. H. Bragg, D.Sc., F.R.S. (Nobel Prizeman), will deliver a lecture on "X-rays and Crystal Structure, with special reference to certain Metals."

# THE JOURNAL OF The Institution of Electrical Engineers

Vol. 54.

JUNE, 1916.

No. 260.

## THE ELECTRICITY SUPPLY OF GREAT BRITAIN.

By ERNEST T. WILLIAMS, Member.

(Paper first received 12 January, and in final form 15 March, 1916.)

### CONTENTS.

- I. Introduction
- II. A proposed Electricity Board for the control of the electricity supply of the country and for the co-ordination of the various electrical interests.
- III. The generating stations problem
- IV. The distribution of electrical energy in bulk.
- V. The distribution of electricity in detail.
- VI. Procedure to bring the scheme into operation.
- VII. Summary.
- VIII. Conclusion.

### I. INTRODUCTION.

As originally submitted this paper dealt with three aspects of the subject of "the electricity supply of Great Britain," viz.

- (a) A review of the present state of the electricity supply industry ;
- (b) A review of the new conditions brought about by the war and of the urgent need for electrical engineers to work together for meeting the country's need for a cheaper and more extensive electricity supply ; and
- (c) A proposed scheme to meet this need.

The Council's decision to hold a general discussion on this important subject made it desirable to reduce considerably the ground covered by the introductory paper, and for this reason sections (a) and (b) have been almost entirely deleted. The subject is a difficult one and we cannot do better in its consideration than endorse the decision of the Council by striving in our discussion to seek a basis on which we can take united action in the future. There is no need to defend any policy advocated in the past ; in fact it is best to leave the past behind—the needs of the times demand it—and press forward in a new spirit of compromise and achievement. Thus if in our discussion we can replace the abstract and negative by the practical and constructive much will be gained. It is not important to have to sacrifice our views on the smaller issues if by so doing the greater aims are made more possible of realization.

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The progress of the electricity supply industry has been one of fairly defined stages, viz.

- (1) Small private plants.
- (2) Larger plants supplying a group of consumers.
- (3) Supply undertakings dealing with very limited areas.
- (4) Town supplies absorbing many of the smaller systems in outside areas.
- (5) Power schemes.

The time has now arrived when we must think of the supply industry not as a large number of independent detached schemes having separate areas, but for the country as a whole. The same circumstances and arguments which have caused the evolution in the successive stages mentioned can be applied with equal or greater force to the next stage. If the policy of centralizing the generating plants in larger power stations has been economically sound, even though this involves transformation losses and additional mains, then why should we hesitate in taking the next logical step of considering the eventual replacement of the large number of small, costly, comparatively inefficient electric supply stations by a few modern interconnected power stations for dealing with the electricity supply of the country as a whole ?

Such a method of dealing with the problem would result in the following advantages :—

- |  |   |
|--|---|
| (1) Lower capital costs per unit of output due to ... .. | <ul style="list-style-type: none"> <li>(a) Cheap sites,</li> <li>(b) Reduced expenditure on buildings,</li> <li>(c) Large generating units,</li> <li>(d) Decreased percentage of reserve plant.</li> </ul>                            |
| (2) Lower working costs per unit due to ... ..           | <ul style="list-style-type: none"> <li>(a) Higher load factor,</li> <li>(b) Higher plant factor,</li> <li>(c) Lower fuel costs,</li> <li>(d) Lower establishment and labour charges,</li> <li>(e) Lower maintenance costs.</li> </ul> |

Against this must be set the increased cost of bulk distribution mains and transforming plant, and the loss in efficiency due to the transformation.

If we are to attain something of the position clearly possible for the electricity supply industry, it will be by taking Great Britain as a whole and so ordering our development from year to year that by gradual steps the transition from the present conditions to those suggested will be economically brought about.

The area of Great Britain is comparatively small, but no country offers so great promise for a sound and economical electricity supply if taken as a whole.

In considering this problem we may divide it into three main sections, namely,

- (a) Technical considerations ;
- (b) Financial issues ;
- (c) Basis of organization.

After careful consideration and much thought the author has come to the conclusion that the first of these sections offers the least difficulty, and that the second is one in which we can largely be guided by present experience and knowledge. It is the third section, "the basis of organization," which most urgently demands our attention. The more deeply we consider the subject the more apparent and convincing does it become that it is the fundamental principles of organization and establishment which must be settled on a sure foundation, if we are to make the best progress and see the consummation of the ideal for which we aim. This solved, then the solution of the technical and financial considerations would, in the author's opinion, soon follow. It is for this reason he has endeavoured to evolve a scheme on which the organization might be based, keeping in mind the technical and financial issues and the existing capital and interests involved.

It is not assumed that the proposals herein made give the ideal arrangement. We cannot start *de novo* and ignore, even if we wished to do so, what has already been done, the capital invested, the natural prejudices and interests and the human factor all closely bound up with present achievement. It is only right that we should recognize that the prominent position occupied by the industry and the splendid progress of a few short years have been due to the courage, energy, and foresight of those engineers, and others, who have been the pioneers. The honour due to them we fully concede, and the right of vested interests we clearly recognize ; yet while doing this we need not, nay we must not, lose sight of the fact that the electric supply industry is *not* on the most efficient or satisfactory basis and is not playing that fuller beneficial part in the lives of our people that it deserves and that they have the right to expect.

Proud though we may be of the advance made in the past, certain it is that our national inertia and the misapplication of our individualistic tendencies have greatly retarded progress. In what way can the recognition of these and other failings be brought to have a beneficial influence on the future ? On our finding the answers, and adapting them to our own work, will depend the part we shall play in averting some of the more disastrous aspects of the aftermath of the war and in relieving something of the desolation that must follow. It is the duty of every

profession, trade, and industry to study the problem without delay and organize in its own sphere for the common good. The call of the broken soldier, the bereaved family, and the ruined business-man will cry out to us to do something better than we have achieved in the past. It behoves us then to look ahead, and scientifically and with foresight lay out our plans to meet future needs as well as present requirements. It is imperative that any scheme proposed shall be formulated to draw in existing interests on our behalf instead of acting in direct opposition to them.

## II. THE PUBLIC CONTROL OF ELECTRICITY SUPPLY.

The public control of electricity supply is at present vested directly in Parliament, in the Board of Trade, in the Local Government Board, and in the Home Office. It is desirable for the highest success of the scheme as a whole that this control shall be co-ordinated by a central body directly responsible to Parliament. It is most desirable that such a body shall not be an existing Government Department having various other interests ; also that it shall not be a Government Department at all in the accepted sense of the word and acting under the multifarious restrictions with which Government Departments are essentially bound. At the same time this central body must have all the weight of Government authority and be able to authorize or raise big loans on Government security at low rates of interest.

Suffice it to say that there does not exist at present such a body and that one would have to be created with the necessary powers under Special Act of Parliament. Such a body could be designated the Electricity Board and by it could be controlled the whole of the electricity supply problems of the United Kingdom. The *raison d'être* of such a board would be the co-ordination, control, and development of the electricity supply of the whole kingdom for the public good.

The constitution of such a Board would be important, and in order to consider more clearly what its composition and scope would be, one may assume that the whole country of Great Britain is divided into say six sections, viz. the South-East (including London), the South-West, the Midland, the North-East, the North-West, and Scotland. Whether this is exactly the most suitable set of divisions matters little for the purposes of this paper, but it forms a basis on which the whole scheme can be considered.

An electrical engineer manager would be appointed for each district, where he would reside in a central position. On him would devolve primarily the responsibility of seeing that the best interests of the electricity supply for the public good were being developed and maintained, and in him would be co-ordinated the various electrical interests of the district and the management of such portion of the electricity supply as might be directly handled by the Electricity Board.

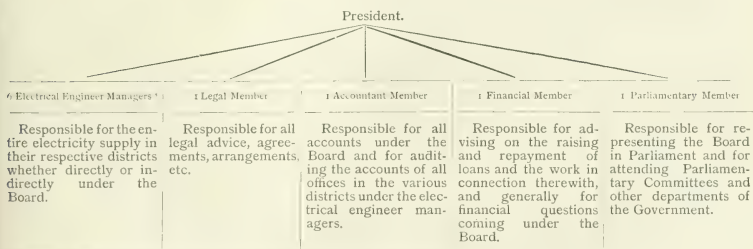
One of the most interesting examples of a new quasi Government Department is that of the Public Trustee, whose great and rapid success proved the value of having a faithful and sympathetic public servant available for certain purposes. The electrical engineer managers would act in a similar way in their own districts, whose electrical well-being would be their primary interest and endeavour, and these gentlemen holding well-paid and authoritative

positions would be members of the Electricity Board and take part in all its deliberations.

Such public Boards to be most efficient should be kept as small in size as possible. It is, however, desirable that they shall be self-contained and fully representative of the departments of the Board. Such departments would be the legal, the accounting, the financial, and the Parliamentary. The legal would deal with all legal questions coming under the purview of the Board or its electrical engineer managers, who would have the value of direct and free appeal to the responsible legal authority at all times. Similarly the importance of audit and accounts which would come under the Board in many ways would make this an important department. The vast financial interests, the raising and repayment of loans, and other financial transactions would necessitate a financial department. The Parliamentary representative would be a sitting Member of Parliament who would represent Parliament on the Board and the Board in Parliament and deal generally with Government Departments. The heads of these four departments, like the electrical engineer managers, should be men of authority and repute in their several professions, so that the Board constituted of these ten and two other members, would represent an efficient and responsible body of high permanent officials and recognized experts.

It would be desirable that the President of the Board, at the outset at any rate, should be a man of wide knowledge and experience in public affairs, and a man whose name carried weight and confidence with the public and men of affairs. Like the other members he should preferably be a paid official and expected to devote most of his time and interests to the work of the Board. Finally the Board would have its permanent Secretary in whom—under the President—the organization would be centralized. This is shown diagrammatically in the following diagram:—

#### PROPOSED ELECTRICITY BOARD.



To the Electricity Board proposed in the foregoing clauses all the questions relating to the electricity supply of Great Britain would be referred. It would become the Authority—under Act of Parliament—on all the various questions and issues involved in the supply and application

\* One of the electrical engineer managers would be the vice-president of the Board.

of electricity. Matters now dealt with by the Home Office, the Board of Trade, the Local Government Board, and by Parliament itself, would be gathered together under its control. The only reservation would be the right of appeal from the Board's decisions to the higher authority of Parliament.

#### III. GENERATING STATIONS.

Never before in the history of our country has it been so evident that we must conserve our capital and resources. Thus, to launch forth on to theoretical considerations of the generation of electricity without using to the utmost the present sources of supply would be to court failure. Various illustrations could be given to show that most successful undertakings have grown or evolved from small beginnings, and though theoretically and on paper it might be possible to make a case for a "clean sweep" of the old and an entirely fresh start under modern conditions, yet evidence and experience tend to discount such a view.

The suggested scheme would therefore at the outset interfere with present generating stations to the minimum extent. When, however, stations under municipal control reached the limit of their capacity, or desired to replace their obsolete plant, they would require to obtain the Board's authority for the expenditure. It would then be for the Board to decide in each case whether the interests of the district and of the electricity supply of the country as a whole would best be served by allowing such additional plant to be purchased by the Corporation and installed in the generating stations, or whether it would be better for the additional load to be supplied in bulk from a bulk network.

It would be for consideration whether limited companies should be brought compulsorily under this ruling or not, for they are placed under different conditions from municipalities and generally would prefer to purchase their

current in bulk, if by so doing they could obtain it at a lower cost, than to sink further capital in their existing generating stations.

The author has referred to a bulk network—what stations would feed into this network and under whose control would they be? It is known that there are several large stations in the country which are highly efficient, modern,

and capable of extension in large units. These stations would be the initial ones in the greater scheme which would be planned in order to embrace them. They would be interconnected by a bulk-supply network into which they would supply their surplus power. Though additional new stations would be required from time to time as the demand increased, and it would probably be preferred for such stations to be erected and worked directly under the Board, yet it by no means follows that the control of the existing power stations which it might be decided to incorporate into the scheme should pass out of the hands of the present authorities whether municipal or company owned.

Looking into the future we can see a number of very large power stations, mostly owned by and worked under the Board, supplying into a bulk network spread over the country. Some of these stations would have been large ones purchased from the present owners and considerably extended. Other stations feeding into the network would be those which had remained under present owners who would be able to generate on a sufficiently large scale at such economic figures that they would be able to sell their surplus output to the Board at prices to compare with the cost of generating at the Board's own stations. This would enable waste blast-furnace gas, surplus water power, and other sources of energy to be utilized.

It does not require to be demonstrated that the lower the price at which we can supply electric energy the greater will be the demand, and conversely, the greater the demand the lower the cost at which we can supply. The result is thus cumulative, and it is safe to say that if the cost can be brought low enough the demand will be so great as absolutely to dwarf the present load. The two chief items of generating cost at present are the capital charges and fuel, and it is very evident that under favourable conditions and with a sufficient demand these can be reduced to a small fraction of the present average generation costs throughout the country.

Important as are the capital and working costs per unit, there is a third item which has a direct bearing on these, and one which the scheme would take full advantage of; this is the plant factor and the load factor. It can be taken as a *sine qua non*, with security from stoppage of supply and low charges, that practically the whole of the electricity demand in the country would fall on these stations. With the diversity factor of such a demand the load factor on the stations would be high. The plant factor, or proportion of time the plant when running is on full load, would be almost unity. This would be brought about by the interconnection of the stations.

Under the scheme outlined we do not interfere with the present stations and the capital invested in them. Those stations which after full and due consideration it is proposed to incorporate in the scheme, would quickly grow with much greater units, while generally those stations which are not to be included in the final scheme will continue to use their plant until it has outgrown its useful economic purpose, when its place will be taken by transforming apparatus, and there will thus be a gradual transition of these generating stations to transforming stations and depots.

A marked feature of the scheme would be that it should enable much greater freedom of departure from "cut-and-

dried" methods to be embarked upon. This would be due to the fact that a station could be laid out and built on a large scale at once, for, if it is to feed into a network to supply the whole country with a rapidly growing demand, the time would be comparatively short before the station would be required to give its full output. Thus early utilization of the capital sunk in the station would remove one of the disabilities under which the designer of an ordinary large power station now labours. More important, however, would be the fact that the failure of any new departure to obtain fully the anticipated results would not be the same serious matter which a similar partly successful experiment would be on an ordinary power scheme to-day. The proportion of one station, the design of which was a departure from standard plans, to the stations for the whole scheme, would cause the resulting detrimental effect of only a partial success to be divided over the whole, thus the engineers responsible would not hesitate as they now must in venturing on untrodden paths. This is important, for development must be progressive, since the discoveries of science constantly open new fields for exploitation.

A number of the stations would probably be arranged for running on gas-fired boilers with modern plant for the production of the by-products of the fuel in large quantities, and near to such stations would probably be established chemical production companies making large demands for electrical energy for electrochemical processes.

#### IV. BULK DISTRIBUTION.

The third item of electricity supply is the "distribution of electricity in bulk." For convenience of reference one may divide the bulk-supply network into main and subsidiary. The main network should be the property of the Board, which with its powers would have the right to carry its overhead or underground mains through any district. The subsidiary network might belong either to the Board or to existing undertakers according to circumstances; for example, there appears no reason whatever why the power companies and the large municipal undertakings should not themselves supply current in bulk on their own mains, taking the supply from their own power stations, from the Board's bulk network, or from both.

The bulk network would have to be designed with a view to ensuring reliability of supply, so that if any one power station failed it would not affect the main supply, or if any one section of the bulk network was destroyed the supply of current would go on automatically to the subsidiary network. This reliability of supply is of the utmost importance, taking the premier place even before low cost. In the past we have seen disastrous results due to large power stations or bulk networks failing, and one of the strongest arguments for the new scheme would be its greater reliability, owing to the number of stations and the alternative routes of cables. If the railway and large industrial power demands, mines, pumping stations, docks, etc., are to be entirely dependent on the electricity supply of the country, that supply must be absolutely reliable and capable of meeting the exigencies of all possible cases *save force majeure*.

There is a further reason why the bulk-supply network generally should come directly under the Board, and that

is because the question of giving a supply in any part of the country will require to be regarded not alone from the standpoint of whether it will pay to run the electric mains for the immediate demand, but also from the larger standpoint of whether giving such supply is for the good of the country as a whole. In this way many districts would be given a cheap supply of electricity which under the ordinary commercial conditions of a company operating in a smaller area would not obtain.

#### V. THE DISTRIBUTION OF ELECTRICITY IN DETAIL.

Finally we come to the transformation and distribution of electricity in detail; that is to say the last step in supplying current to the small and medium size consumer. On the whole this place is being well and efficiently filled by the present undertakings and, with the exception of removing a few anomalies and arranging for developments to be on lines which will tend to greater uniformity throughout the country, the scheme would not interfere with the present arrangements. It is in this direction that we shall obtain the support of the present supply authorities, viz. by letting them retain those parts of their own undertakings which are essentially local. It matters little to them whether they generate their own current or receive it as a bulk supply at a much lower cost, but it does matter to them very much whether their undertaking is taken over or not.

Again we meet the human factor in this matter, which it would be fatal to ignore, for if those at present interested directly or indirectly in the existing undertakings can clearly see that the scheme will not be detrimental to them, but otherwise, we shall readily receive their support. Take, for example, the electricity supply of a town with a generating station which would not be absorbed into the scheme, but which would gradually change into a transforming station and depot under the same control whether municipal or company. By that date, and with the help of the cheap bulk supply obtained from the Board, the electricity undertaking would have far outgrown its present importance, so that all the energies of the present and additional staffs would be absorbed in dealing with the transformation of the bulk supply and its distribution throughout their area. When we consider that practically all indoor and outdoor lighting will be effected by electricity, also that most mechanical power, conveyances, cooking, and heating will be electrical, and that the present areas of supply will generally be considerably extended, the importance of that town's electrical undertaking will be comparatively much greater than at present.

By leaving the local distribution under local control, the inter-departmental questions which arise, such as opening roads for laying mains, lighting roads, pumping water electrically, etc., would be more readily dealt with, and, perhaps more important than all, having local control, whether municipal or company, would create a local interest in the question of electricity supply which would tend to its more rapid and favourable development.

There are, however, some districts where there are no present electricity supply authorities, and if the Board failed to get these districts taken under the wing of some existing or new undertaking, the detail distribution

would have to be carried out by the Board itself in order that no district in the country would be without its cheap electricity supply. This will not be a difficult matter, for undoubtedly under the new conditions all the railways, main line and suburban, would eventually be electrically operated, and this would carry the electricity supply wherever there was a railway, from which the supply would radiate to the country around.

It is readily realized that this desirable state of things will not be brought about in a day and that progress must go hand in hand with sound finance and common sense, but once the whole scheme is firmly established it will be easily able to bear the small burden of these possibly non-paying districts, just as many of the present undertakings supply to outskirts which can hardly hope to be remunerative.

In the author's opinion one of the indirect results of the scheme would be the resuscitation of our canal system. Canal routes would in many cases be suitable for carrying distributing networks into various districts, and cheap power alongside the canal would increase the value of the land adjoining both for agricultural and industrial purposes. The use of cheap power would soon make itself felt in the development of mechanical propulsion on canals, and there can be no doubt that a revived and efficient system of transit along canals would be an economic factor of great importance to the country. Hitherto, the question of electrical propulsion has been partly held back by the cost of the electric power system, but when power mains are running along canal routes for other purposes the problem will be simplified.

Similarly the great agricultural interests of this country, which it is so important to revive, would receive a great stimulus from a cheap electricity supply. In other lands electricity is being largely adopted in agriculture; and much is to be gained by its aid for lighting, power, heating, and transport. Not only directly but indirectly must we assist agriculture by reducing the cost of artificial fertilizers, whether as by-products of generating stations worked with gas-fired boilers or through the cheap supply of current to electrochemical industries.

#### VI. PROCEDURE TO BRING THE SCHEME INTO OPERATION.

It is felt that the time is now ripe to launch this or a similar scheme on to the public notice. There is evidence on every side that men's minds are already actively employed in considering what can be done to enable the nation to support the burden brought about by the war. In what ways can the nation prevent waste and economize, and in what manner can production be increased? Fortunately the electricity supply problem can play a leading part in both these departments, and because of this there has never been a more favourable time in which a united electrical profession could rapidly obtain public interest in and public support for its schemes. In the words of the Right Hon. A. Bonar Law, M.P. :—

"I hope (they) will realize that the war has made a great difference, that it has made everything plastic, that things which were impossible before are easy now, and that above all it may be found that a big step is not more difficult than a small one."

Or to quote the Right Hon. Edwin S. Montagu, M.P., Financial Secretary to the Treasury :—

"Though no man could say that the only end of the war which was tolerable to us was in sight, yet we ought to see that we were prepared to think of all the enormous problems which awaited us when the war was over. . . . Be prepared to find coming out of the war a different world from the world which went into the war, and be prepared therefore to search your hearts and your minds as to the steps which you desire your country to take when we rebuild what has been devastated by a war into which we were forced."

Enough will have been said in the foregoing pages to enable the general lines of the suggested method of dealing with the problem to be understood, or at any rate to enable us to form a basis for the fuller consideration of the subject. Presuming the general consensus of opinion to be that there is certainly much room for improvement and that the electricity supply of the country should be dealt with as a whole, the next stage would be to bring about, without delay, the first practical steps towards its realization. There is too much said and written in these days which brings no results. Let us determine it shall not be so in this case.

When it is understood that these proposals can be brought into early operation by Act of Parliament without disturbing existing concerns, and that the policy of the proposed Board would be to become self-supporting at no distant date—ultimately neither requiring any financial assistance from the Exchequer nor operating for profit—it would probably receive the immediate support of all political parties and a Bill could be rapidly passed through Parliament. In fact the author considers we can safely say that it would be welcomed as evidence that the country had commenced to move on progressive lines, and far from being considered a secondary matter to be put back till after the stress of war, it would be taken in hand early as a convincing argument that the powers that be are not blindly leaving the future to take care of itself.

In a paper read before the International Engineering Congress, San Francisco, last summer, Mr. C. H. Mitchell demonstrates the wisdom and success of the policy of the Ontario Hydro-electric Commission. In this Commission is embodied, by Act of the Canadian Parliament, the control of the electricity supply of the Province of Ontario. Briefly the Commission is the medium through which the electricity supply of Ontario is co-ordinated. Its aim is to enable electricity to be given at the cheapest rate to the people; and it supplies, without profit, electricity in bulk to various supply authorities, obtaining this supply largely from existing power companies and distributing it through the Commission's bulk-supply mains. The costs of the Commission's operations are borne by the authorities to whom the supply is given. The formation of the Commission was considerably criticized. Its remarkable success speaks for itself, and should any further argument be necessary it would form a convincing one for the scheme herein outlined for Great Britain.

Whilst the whole subject requires to be handled in a complete and comprehensive manner, yet it is most desirable to keep in mind the main issues and not to introduce various questions and complications with which it will be the business of the Electricity Board to deal. We should

avoid large committees and voluminous reports, and by keeping the subject on concise and clear lines and dealing with it in a businesslike manner we shall more readily attain our end.

A possible sequence of procedure is suggested as follows:—

(1) Discussion before the Institution, Technical Societies, and in the Press.

(2) The formation of the Preliminary Committee of the Institution with representative outside members to draw up a report and proposals for presentation to the Prime Minister.

(3) The prompt consideration of the report and proposals by a Parliamentary Committee with the assistance of the Preliminary Committee.

(4) The presentation of the Parliamentary Committee's findings to the Cabinet.

(5) Consideration by the Cabinet, and if approved a Bill to be drawn up without delay.

(6) Passing of an Act of Parliament.

(7) Formation of the Board.

## VII. SUMMARY.

It should be clearly understood that the proposed scheme is not for the nationalization of our electricity supply, nor is it for the municipalization of that supply. Its true function is the co-ordination into one body of the control of the electricity supply, assisting existing undertakings whether municipal or company owned, and taking upon itself only those functions of generation and distribution which are essential to the furtherance of wise development and a supply at the lowest cost.

It should also be clearly understood at the outset that the scheme proposes no confiscation of the rights, privileges, and property of either electricity companies or municipalities, and in the event of its being recognized as essential in certain special cases to take any of these over, that full compensation shall be paid not only of the value of the actual plant but of reasonable allowances for potential values. This course is considered to be the only sound, logical, and equitable one; for while on the one hand it will prevent a number of undertakings with obsolete plant being put as a burden on to the shoulders of the Board, on the other it will remove all fear of unfavourable or detrimental treatment from those authorities or companies who have been successfully working for present and future results.

In order that these principles shall be ensured, they would be embodied into the proposed Act of Parliament under which the Board would be formed and would act. In other words it is not proposed to set up an arbitrary organization which will act as though the present state of the electrical industry required radical and sweeping changes and the overcoming of existing interests—no—rather the whole basis and policy of the organization will be heartily to recognize what has been done by the existing authorities whether public or private, and, instead of sweeping away, to conserve and build up, guiding future policy and co-operating with the present authorities for the well-being of the whole.

In the past there have been three schools of thought, each advocating its own policy as the best. These are, first, those who would nationalize all public institutions

of any kind. They do not realize the enormous success and courage of private enterprise and the extent of indebtedness of the country to it. They see some obvious failings and propose nationalization as the cure for all ills. They fail to see or understand the essential restrictions and limitations of national institutions.

Again, those who have advocated municipalization to the exclusion of other control, have been able to make a good case in many instances from one standpoint only, what we may term the local or limited outlook, as opposed to the larger one embracing the country as a whole, or as ignoring the failures as a set-off to the successes of municipalization.

Then there has been the third school which has determinedly set its face against public institutions interfering with private enterprise, clearly pointing out that the duty of the State should be limited to governing, and that all development and financial risks should be left to the public in its private capacity, with its liberty of action and freedom from restrictions which hinder progress.

The author of this paper having occupied responsible positions in Government, municipal, and private concerns, and having seen the inner workings of each, ventures to submit the opinion that each has its proper sphere of action which it alone can best perform, and that the highest efficiency and greatest progress are only attained when these interests work together in the common cause, none trying to usurp the place of the other but all recognizing that the success of the whole means success of each in its own department. No better illustration of the success of this compromise in concerted action could be given than the success of the British colonial policy. It is in this way that our new electrical era should be built up, and the proposal for the Electricity Board advocated in the scheme, acting on certain well-defined principles of operation and gathering together the various electrical interests, each and all working for the common good with strict justice, would appear best adapted to meet the case.

If the Electricity Board is established it is quite possible that for a time the policy might be followed of letting each district develop independently, but on a predetermined plan, until the gradual interconnection of all the districts is brought about as a matter of expansion, rather than that the interconnection shall take place first and the expansion follow. It does not by any means follow that because a Board is created it must at once carry out its plans for full development of the whole scheme.

The fact that the initial operations of the Board can be undertaken without huge financial operations is one which will meet with public support and favour, and the avoidance of drastic proposals for sweeping changes either in the ownership or control of existing undertakings

would cause otherwise potential opponents to become adherents and advocates of the scheme, for all thinking men realize that something should and must be done to place the electricity supply of the country on a sounder basis.

#### VIII. CONCLUSION.

There is in the breast of every man worth the name the patriotic instinct—the desire to do something for that country which has done so much for him, and to exert at least some influence in continuing its evolution to better things. Similarly in every true professional man there is a love of his profession and a Divine discontent and reaching out to secure a fuller place in the service of mankind of that branch of science which he has made his life's calling.

Unfortunately, there are times when the mists come over the earth and the highest plane of patriotism and professional aspiration is obscured and we roam in the most circumscribed and narrow valley of personal and local interests. In such circumstances, schemes which call for a wide outlook and lofty endeavour do not stand the same chance of realization or success. But times such as we are now passing through dispel the mist somewhat, and by the sacrifice around us we are lifted to nobler desires and worthier purposes. Problems which but a few months ago would have been crushed at their inception are now seriously and sympathetically considered. Those whose duties have kept them from the Front must soon realize that their great part is in preparing for after the war, when heroic endeavours will be required to build up again that which has been destroyed. Does not the very soul of our profession yearn to establish the electricity supply of the country on the best basis for assisting this work of reconstruction and alleviating something of the distress which even the greatest optimists foresee in the future?

And while we build may we not hope to work to a better plan? Can we not see the dawn of a new era when an efficient electricity supply at low cost and with the new means of transport will enable men to work under better economic and more humane conditions in the country, instead of extending the already densely packed towns? A future in which we shall be conserving our resources to the utmost and by greater efficiency be preparing for the next war, which will be industrial and waged between the economic forces rising both in the East and in the West.

Finally these days of grave responsibility are also days of great privilege and opportunity. Never again shall we find the same mental and moral attitude which is necessary to bring some such a scheme as here outlined to early fruition. Let it not be said of us that we failed.

## DISCUSSION ON

## "THE PRESENT POSITION OF ELECTRICITY SUPPLY IN THE UNITED KINGDOM AND THE STEPS TO BE TAKEN TO IMPROVE AND STRENGTHEN IT."

BEFORE THE INSTITUTION 13 APRIL, 1916.

Mr.  
Williams.  
Mr. Merz.

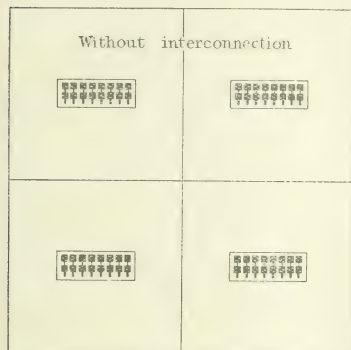
The discussion was opened by Mr. E. T. WILLIAMS who read an abstract of his paper (see page 581) on this subject.

Mr. C. H. MERZ: I wish that Dr. Ferranti had been here to-night to take part in the discussion, for he certainly was the first to suggest that electricity supply throughout the United Kingdom should be from one comprehensive interconnected system. It is well that we should consider why this ideal, which was first put forward by him in substance 20 years ago, has not made greater progress. The situation has been reviewed before numerous Parliamentary committees and otherwise; there have been endless schemes for attaining something of this ideal, perhaps not for the country as a whole, but for large districts, and yet we have not made much progress. I think it would be well to face the facts and ask ourselves why we have not made more progress. Mr. Williams has suggested that both the technical side and the financial side are simple, and that the difficulty is one of organization, but I beg to differ from him. The reason why this ideal has not made more progress is, I think, because the profession as a whole is not convinced that it is the correct one. The Institution has primarily to deal with technical matters, and we had better begin by settling whether some of us are wrong and the rest are right, or vice versa. We ought to try and settle whether this ideal of the general distribution of electricity is not something to which we may hope to attain. To begin with, we must once for all make up our minds that we cannot argue that something is right for this country because it is done in other countries, or that something is wrong for this country because it is wrong in other countries. I have travelled a good deal abroad, in America and other countries, and the more I have travelled the more I am dissatisfied with the average English engineering attitude, which may be said to be: why cannot we do so and so because America does it, or because Germany does it? That seems to me to be a very low level on which to discuss a question. Certainly it was not the standpoint which produced the engineering industry of this country. I would suggest that we, as an Institution, if we are going to consider the whole situation, ought at once to get rid of any idea that it can be proved from the experience of other countries what can be done in this country. Our aim now, if it has not been so in the past, ought to be to lead and not to follow. I propose to deal with the technical side because I believe, as I have said, that the industry is not convinced as to how this problem ought to be solved. It seems to me to be a fact that, as regards electrical distribution, the United Kingdom, and especially England, is in an absolutely different position from any other country. If we go into that question we shall find that it is really one of geography. England is very different geographically from Germany and totally different from the United States, and a wrong conclusion would certainly be arrived at if we determined the general

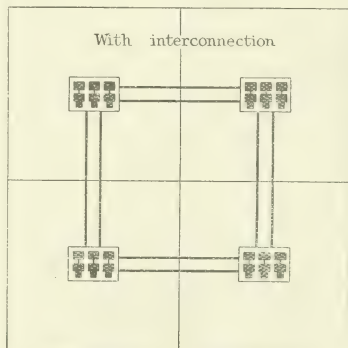
question of interconnected electrical distribution throughout the country from experience gained in America. England as a whole is very much more congested, and the congested areas are very much closer together; and the same characteristics of the country as regards population and distance which seem to me to point emphatically to electrical operation of the railways within a reasonable time, point also to a general distribution system. I do not believe, however, that even that tells the whole story. I think the present war and the general conditions of electricity supply emphasize the importance of one of the matters which have been particularly referred to by the author, namely, the question of security of supply. So long as it was a question of supplying a certain area from a power station the capacity of which might rise to 5,000 kw. or thereabouts, this question did not come very prominently forward; but we have advanced so far in this country that in many areas we are getting to the condition where considerable communities depend upon electric stations for their supply of power and light—the maintenance of which supplies is vital to those communities. Speaking generally, throughout the country each area depends to-day upon one central station. Now, speaking frankly, I think that is a state of affairs which if we, as an industry, allow it to continue, will get us into a muddle; there will be a serious collapse of some kind. I think it is certain that the more a given area depends upon electricity supply the more important will it be that it should not depend on a single station. Fig. 1, prepared some time ago, illustrates the advantages of interconnection. The four sections on the left show the system which is being adopted or aimed at to-day in this country. It is quite a usual arrangement. As the load increases, a point is reached where a new generating station is necessary, and the standard practice in this country would be to put down a station arranged with say 5,000-kw. sets, or some such size, capable of gradual extension. Perhaps four or five are put down to commence with and they are gradually extended to eight. We should then get an area supplied from a 40,000-kw. station containing eight 5,000-kw. sets, two of which might be considered to be spare; thus the station deals with a maximum load of 30,000 kw. That area entirely depends on one station, and if anything were to happen to this station, either due to an accident or to a bomb dropping on it, or through some interference with the coal delivery system or the circulating water system, a very serious state of affairs would exist in that area. The way in which Dr. Ferranti and a good many of us would say that that series of areas ought to be dealt with is diagrammatically shown on the right half of Fig. 1. In each area is placed a larger station than before of 45,000 kw. containing three sets of 15,000 kw. each. Those are interconnected by a trunk system of mains, and we thus get an area equal to the four areas

shown in the first diagram but supplied by four generating stations, each station containing 45,000 kw. of plant. We get a load on each station as before of 30,000 kw.; one complete spare station for the four areas; four spare sets as against two for each area in the first case; certainly lower capital cost, and very much lower operating costs. That diagram roughly represents the way in which I maintain the general question of electricity supply ought to be considered as regards this country, and the first thing we must do as a technical Institution, if we are going to consider the question raised

independent stations. Actual plants are being laid out and built to-day which will attain such results. I know it is commonly said "If we double the size of our generating unit we can only get a 10 per cent improvement." That is not so. It is impossible to enter into a discussion now as to what is actually involved in designing a large station on the most up-to-date lines, but putting it generally, every day it is becoming more and more apparent that with the small station we cannot go in for the refinements or the special apparatus necessary in order to obtain the highest economy. One other question is, I think, of paramount



Each area is assumed to have a peak demand of 30,000 kw.



Each area is assumed to have a peak demand of 30,000 kw.

Capacity of each of the 4 generating stations = 8 sets of 5,000 kw. each, = 40,000 kw.  
Load on each station = 30,000 kw.  
Spare stations = 0.  
Spare sets (in each station) = 2.  
Spare capacity (all in one station) = 33 1/3 %.  
Capital cost = higher.  
Operating cost (fuel and wages) = higher.

Capacity of each of the 4 generating stations = 3 sets of 15,000 kw. each, = 45,000 kw.  
Load on each station = 30,000 kw.  
Spare stations = 1.  
Spare sets = 4.  
Spare capacity (in 4 stations) = 50 %.  
Capital cost = lower.  
Operating cost (fuel and wages) = lower.

FIG. 1. -Diagram showing plant required to supply 4 different areas by means of separate stations, as compared with that required to supply the same area, if power stations are interconnected.

by Mr. Williams, is to decide whether that general principle is right or not. I am satisfied in my own mind that it is the only logical way of proceeding if we wish to obtain reasonable security of supply, because the extent to which a given area is tending to depend on electricity is becoming too serious to allow of its being supplied from one station; whilst, on the other hand, to put up two stations in each area would be too expensive. That diagram was prepared some time ago; to-day perhaps it would have been better if I had taken 7,000-kw. and 50,000-kw. sets. At any rate I am satisfied that with such an interconnected system and with the larger generating sets which can be designed to-day we can obtain a saving in coal consumption per unit of from 30 to 60 per cent compared with what can be done by small

importance in this connection, namely, the importance of the improvement in load factor which results from connecting up big areas. Some years ago it was often stated that it was an impossibility to obtain a load factor of anything like 60 per cent by the interconnection of supply areas, but experience on the North-East coast shows conclusively that one is able by such means to raise the load factor to 60 per cent and over. So I would put it very strongly to the Institution that the first thing necessary, if any alteration in progress towards the ideal of an interconnected system for this country is to be made, is for engineers to agree among themselves as to whether this is the right line of development. I do not think we can expect Parliament or the Government to deal with this matter in the near future—they will have far too much to

Mr. Merz.

do. Secondly, if we could persuade them to deal with it, how could we expect them to arrive at a right solution if we are divided amongst ourselves as to how the matter ought to be tackled? What is wanted—and here I think we might borrow something from other countries—is to get it to be a fashion to deal with such a question as electricity supply by certain methods. Unless we can get it to be a fashion among the industry as a whole we shall not make any progress. They manage to develop technical fashions very well in America, to the great advantage of everyone in the industry; we want to get it to be the fashion in this country for electrical engineers to deal with their generating and distribution systems in the same way and on the same principles as we ask our consumers to deal with their loads, viz. to couple them with an interconnected system. If we could do that we should accomplish a great deal and we should make some real progress.

Mr. Chattock.

Mr. R. A. CHATTOCK: I am interested to see that Mr. Williams' proposals are very similar to those that I recommended about two years ago in my Address to the Incorporated Municipal Electrical Association.\* I feel, however, that he has not sufficiently emphasized the real justification for a scheme of this kind. The whole problem seems to me to turn upon the necessity for attracting consumers; and the only way in which that can be done is to reduce the cost of supply and the prices consumers have to pay. I was amused at Mr. Merz's suggestion that we ought to stimulate a fashion in getting these supplies taken up, but I do not think the average British manufacturer will trouble about fashion if it is going to affect his pocket. What he wants is a cheap and reliable supply. There is no doubt that the reason why manufacturers in large industrial areas have taken supplies from public authorities and companies is that they feel they can rely upon such supplies and that the prices offered are becoming more tempting every year. Now it is our business to stimulate that idea and to follow it up, and I think the lines which Mr. Williams has put forward will undoubtedly further that end. It is quite true that the industrial areas in this country are very large and very congested, but there is an enormous amount of power and other branches of supply in those areas that has not yet been touched. The electrical energy sold per head of population, for example, is only about one-tenth of what could be done if the supply were developed on the lines suggested; we are, however, gradually approaching that end through the way in which the supply is now being developed. What hampers the development is the large number of small stations in the country where the cost of supply is high compared with what it should be; this is also the case in some of the large areas. I feel that a scheme of this kind should be brought forward and run upon broad-minded lines, not so much with the idea of making large profits but in the interests of the consumers, and, if necessary, facing a loss for some years. In the early days of electricity supply a large amount of pioneer work had to be done by the companies that were then formed; they had to spend a lot of money and received no return on it for many years. Now they are

\* *Proceedings of the Incorporated Municipal Electrical Association, 1914.*

in a sound financial position. If a scheme of this kind is to be developed there is no doubt that money will have to be spent, and that any return on that money must not be expected for a few years. I consider that that burden should be borne by the community itself, because it is really necessary for the development of the industries of the country as a whole. It is not fair to call upon individual companies or municipalities to develop large schemes of this kind and to throw the cost upon the individuals they represent; it should be borne by the whole manufacturing community of the country. Present experience in large towns proves that as the output increases, the cost of production decreases, and it is only necessary to carry that to a logical conclusion to justify fully the scheme which Mr. Williams has put forward. In regard to the technical details of the scheme, Mr. Williams has indicated that we must proceed carefully and not interfere with existing undertakings—that we must let them go on and provide for any extensions that they may require. I do not think that is quite the right way to carry out a scheme of this kind, because it presupposes that these uneconomical stations will still have to be run. I think it is much better, in developing a big scheme of this kind, to face the condition that those uneconomical stations must be cut out at once as generating units, although as distributing units they can certainly be used. I do not see that there is any difficulty in handling different methods of supply in these isolated areas. We can continue to develop the existing methods at present in use, supplying each area in bulk through its own sub-station. I think probably the number of large stations that will be necessary will be quite considerable, and it occurred to me that in practice Mr. Merz's suggestion of four stations linked up is what we shall come to all over the country. Large stations will have to be linked together so that they can stand by each other and get the benefit of large generating sets and the cheapest costs that are obtainable. In my opinion those stations will certainly approximate to 300,000 kw. capacity each, probably more than that in certain cases, because when the cost is reduced and the supply arrives at what one might call a really popular price, the demand that will come upon the stations from the community will be enormously greater than it is at present. I quite realize that a bulk-supply network of this kind all over the country will be a very expensive and probably difficult matter to arrange; but whatever body deals with the scheme it must have power to carry it out on very broad lines with regard to the geographical position of these big centres of industry. It is in those centres that the greatest demand for electrical energy will arise, and of course the larger stations will have to be fairly close to such demands so that the minimum amount of current will have to be transmitted to a considerable distance. I foresee there will probably be great difficulties in obtaining wayleaves for the trunk lines over the country, and drastic powers will probably have to be obtained to prevent the cost of obtaining such wayleaves crippling the scheme. I am afraid that Parliament will hardly be able at present to deal with a scheme of this kind, but that is no reason why we should not develop it and get it ready to be brought forward as soon as the conditions are favourable. I

Mr. Chattock.

think the proper thing to do is to get the best advice possible on the subject, so that when the time arrives we shall be able to go to Parliament with a fully considered scheme. In conclusion, I should like to emphasize how very important it is to the industrial community of the country to have a reliable and cheap supply of power for all purposes.

Mr. J. S. HIGHFIELD: I thoroughly appreciate Mr. Merz's most important statement that engineers, and incidentally the financiers dealing with the question of electricity supply, should come to a general agreement before putting forward a general scheme. That, it seems to me, is of paramount importance; but when Mr. Chattock says that we are not to earn any profits, that we are to raise sums of money on somebody's credit in order to lay mains all over the country, that we are to go back to those dreadful times that we all remember so well at the beginning of electricity supply when we could not earn any profit, I thoroughly disagree with him. It is hopeless to attempt to raise money from the public under such circumstances; and even if it were raised on municipal or State credit, we have still got to find the interest on the capital. No, we must show that we are in a position to put down plant and mains and earn an early profit. Mr. Chattock put the case very strongly the other way, and even Mr. Williams has referred to the fact that we are to trade for the public good. I am convinced that unless the finance of any scheme is sound no satisfactory result will be achieved. I do not agree that the present position of electricity supply in this country is so defective as one would be inclined to think from articles that one reads in the Press and from the remarks that have been made this evening. I think that the supply over large areas of the country is exceedingly good. It is cheap, and the manufacturers take it. I agree with Mr. Merz that it is largely a question of fashion, because the cost of power to many manufacturers is a very small proportion of their total charges; therefore it is largely a question of fashion and not of price. There are very few large towns or even small ones where if anyone proposes to start a factory he will not quickly receive a visit from the electricity supply authorities. I think that to belittle what we have achieved up to the present is wrong. Mr. Merz has shown a very interesting load curve indicating what has been done on the North-East coast, and I do not believe there is any part of the world that can show anything better in the way of electricity supply. What we want to do is gradually to extend the same admirable system, because I agree with Mr. Williams that it is not a matter which can be carried out all at once. I do not at all agree with Mr. Chattock that we should spend a lot of money, on which no profit will be made for years, in erecting four of those large power stations of Mr. Merz's in different parts of the country, and then wait for years until houses and factories are built in the neighbourhood so that we can get a load. We must, instead, gradually collect together the different supplies in the country. We must use discretion in deciding when an existing works should be extended, and even if the immediate financial result is not so good we must consider what the result will be in, say, five or six years' time. It may be better in that time to take a bulk

supply so as to enable large power houses to grow larger, than to make what can never be a big power-house a little bigger. It is a question of the education of engineers. The more they learn to believe in the principle that Mr. Merz has enunciated to-night, the sooner this result will come about. Mr. Williams has suggested that additional legislation is necessary. I think if there is one industry in this country which has suffered from legislation it is ours. Mr. Williams has rather disregarded history, but I think history is all important. Look back over the past and consider the state of affairs connected with the great industries of the country; for instance, agriculture, fishing, shipping, woollen manufacture, and later, railways and gas supply. All those industries have been carried out by private enterprise and whenever the Government has stepped in and tried to help them trouble has generally resulted. I do not like the idea of additional legislation. It is all very well to remove the damage which has been done by past legislation, but I do not want the Government to try and help us. Consider for a moment the very analogous business of railways and gas supply. The railway companies started at any rate with a permanent tenure; there was no question of their being bought out at the end of some particular period. The Railway Acts allowed very free competition; two parallel lines were allowed to be laid down supplying the same towns. This on the one hand resulted in a certain amount of waste of capital, but on the other it brought into the field two promoters instead of one, and two engineers instead of one, and in every department two business people instead of one, and the result was that the development was very much quicker, so that although there may have been waste of capital and a certain amount of unnecessary duplication the final result was good. It is an illustration in favour of allowing competition in the early stages of an industry. In time wasteful competition is usually eliminated with advantage. The gas companies also enjoyed permanent tenure. In their Acts provision was made for protecting the consumer by adopting a sliding scale of prices, and although there are some defects in this method and also in the method introduced in the Gas Acts of raising capital, on the whole it has resulted in good. The electrical companies were hampered from the first by the limited concessions granted. I believe that if the same opportunity had been given to develop electrical undertakings that was given to develop railway and gas undertakings, we should have been in a very much better position to-day. Mr. Williams has proposed the establishment of a Board, but I am not quite clear what he means. I am not certain whether he means a Board something like the Water Board. I do not understand to whom the Board is to be responsible. What I particularly dislike, however, about the new body he suggests, is that it is to have two mutually destructive powers. He first of all gives the Board a very powerful judicial position; if I want to raise any money or to do anything I have to go to the Board for sanction. At the same time, however, he gives the Board power to say: "You are not to increase your station; but you shall buy from us." That seems to me to be an impossible combination. The Board must have one function and not two destructive functions of that sort. If he would remove the second function, i.e. the commercial side of the Board's operations, and restrict

Mr.  
Highfield.

Mr.  
Highfield.

it to the judicial side and the technical side, so that it can act as a skilful guide, such as an improved Board of Trade independent of party politics, then I think it would be a most useful body. It would be a body that would not only be of use to us but to every trade in the country, and if that is Mr. Williams' suggestion I most heartily approve of it.

Mr. Proctor.

Mr. H. F. PROCTOR: I should like to express my hearty approval of the scheme put forward by Mr. Williams. I consider it to be a happy medium as between nationalization, municipalization, and private ownership. One has only to give a cursory glance at the tables of costs that are published, to realize that it is very necessary there should be some overhauling of our present system, or, I would say, our present lack of system. If we consider that in the London area alone electricity is charged for similar purposes by different authorities at prices ranging from 8d. to 3d. per unit, this seems to me to indicate that there ought to be some united effort to bring things on to a more parallel basis. Mr. Williams dismisses the subject of technical considerations with the comment that they offer the least difficulty. I rather differ from Mr. Merz and go even further than Mr. Williams, and say that I believe such considerations ought not to enter into the matter at the present moment. In my opinion the right way to make a start is to form such a Board as Mr. Williams suggests and to let it get out a scheme for the whole Kingdom. Only by appointing such an independent Board can we get the lines properly laid down as to what is the best scheme for this country. For instance, if it is left to the Institution I am afraid there are so many interests concerned that we shall make no progress. The scheme seems to me to have the great merit that it does no injustice to any existing undertakings, whether municipal or company owned. If their costs are sufficiently low they can generate their energy for their own consumption, or of course they can buy from the Board if the Board proves to be the cheaper market. On the other hand, if their costs are low enough they can even find a good consumer in the Board. There is no great difficulty in the matter of changes of management in Mr. Williams' scheme, nor yet as regards his "scrapping" of capital assets. Mr. Chattock has suggested that we ought to face the scrapping of those assets at once. I am afraid that would mean the introduction of a great difficulty and would postpone the scheme almost indefinitely. Mr. Williams suggests that local authorities should be subject to the control of the Board in regard to the expansion of their existing stations. With that I quite agree. He is not, however, equally definite in his dealings with the works of limited companies. If the terms arranged are equitable they should be equally applicable to a local authority and a company. Our endeavour is to advance the cheapening of the supply of electricity in Great Britain, and we should not allow prejudice or the interests of any one undertaking, whether private or public, to stand in the way of that general advancement. We had far better err in the way of over-compensation to those authorities or companies than let the industry suffer. It seems to me that the fulfilment of such a scheme as that put forward would do more to cheapen the supply than is possible by any private effort, and the sooner it is put in force so that

we may all work towards that one end, the better it will be for everyone. Mr. Williams has referred to the utilization of canal routes, and of course the same principle ought to be applied to railway routes and bridges. One very important point which he has not dealt with is that such a scheme as he puts forward might allow the development and nursing of some of the small though desirable undertakings to take place, with the object of creating new industrial areas. I am of the opinion that the railways, canals, coal supplies, and power supplies should all be co-ordinated and organized under one governing body which might be termed a Ministry. Until we get that I do not think we shall be able to reduce our prices to the minimum we are seeking, and we shall not be able to compete with the organized systems that exist in Japan, Germany, the United States of America, and other countries.

Mr. W. B. WOODHOUSE: Mr. Williams is to be congratulated on the manner in which he has dealt with a subject of such great importance to the country as a whole. Those of us who have been working in the past for some reform of present conditions will welcome his aid. He says that electrical engineers should get together and settle some principles. We have heard different views to-night from Mr. Highfield, who seems to see advantages in competing electrical undertakings, and from Mr. Proctor, who would presumably like to municipalize the whole industry of the country. These are extreme cases, and it seems to me the remarks made by Mr. Merz are really most to the point. It is important first of all that electrical engineers themselves should agree as to what is to be done. It is perfectly hopeless to expect that we are going to get the country to follow us, or Parliament to assist us, unless we know our own minds. Mr. Williams has put forward a very complete scheme for electricity supply, but I think we should remember that electricity supply is only one link in a very much bigger problem, that of the fuel economy and industrial prosperity of the country. I believe that the proper utilization of our natural fuel resources cannot be carried out without some gigantic system of public electricity supply. Therefore before anything is done it will be necessary not only for electrical engineers to get together, but also for the chemists, metallurgists, and geologists to meet in consultation. I am glad to say that that good work has been started, and I hope the active steps that the British Association are taking will have some beneficial result. On the broad principle of interconnection and centralization of supply, I hope it may be said that electrical engineers are agreed. As to the organization by which that is to be carried out, and as to the alterations of present legislation, there may be differences of opinion, but if we can subscribe to the broad principle that it is in the interests of the country for the electricity supply to be co-ordinated, interconnected, and centralized as far as possible, I think we have gone a long way. The problem of electricity supply is very much a financial one. Only by cheap capital can we produce energy cheaply. We have to remember that cheap capital can only be got if we have security. We must give the investor satisfactory security and the prospect of a reasonable return, and anything that tends to that end will be to the good. On the other hand, our

Mr.  
Woodhouse.

national and municipal credit is based on the assumption that the funds raised on that credit are invested in undertakings having the maximum security. This can only be maintained by the careful administration of the funds so raised and by the avoidance of speculative trading. It seems to me that if we are going to develop electricity supply in the way I believe we are, a great many large experiments will have to be carried out in conjunction with the chemist, the metallurgist, and other people who extract valuable properties from coal. That being so, it does not seem to me a suitable thing for Government management. For the investment of capital in a trading undertaking under Government management I think it is difficult to make out a case. I do not know what the view of the country will be after the war—whether it will be more sympathetic to the creation of new Government departments than it has been in the past—but in any event I think we might agree that national funds should not be used in trading ventures if a suitable solution can be found in any other way. On the other hand, a great deal of the work is not speculative, and it seems to me that if the State could assist in the financing of these undertakings by way of loaned capital, without taking a part in the management, it would be very beneficial to this development. Mr. Williams suggests that method under the head of State participation, and I am quite in sympathy with him there, provided that assistance can be given without hampering development. With regard to his suggestion that the basis of organization should be settled first, I am afraid I cannot go so far with him. The important thing, it seems to me, is to bring home to the public what the present situation is, what the present evils are, and what the future prospects are. We live in a very democratic age, in which everybody thinks himself competent to form an opinion on every subject, and unfortunately we have to take that into account. The public must be educated to appreciate and support whatever the electrical engineering industry as a body puts forward as the creed or the dogma to be followed. I think this must be the first step to be taken. We shall not get Government assistance; we shall not get improved legislation; we shall not get any real progress, until we agree what we want and tell the public about it, and keep on telling them.

Mr. C. H. WORDINGHAM: I should like to add my congratulations to Mr. Williams to those of others on his paper, the value of which is augmented by the fact that he is able to view the situation from a detached position. I have had a good deal to do in the past with the question of power supply; I have seen it from both sides of the hedge, and I am now looking down from the top of the hedge, *i.e.* from the consumer's point of view. I put forward the first power scheme I think in this country, a scheme which has since developed enormously and has been attended with conspicuous success. I also opposed very strongly with my evidence the first power-supply scheme to be brought before Parliament. Lately I have been in the position of a consumer, and I must say that the opinion I formed at an early period of many of these power companies has been strongly confirmed; I am convinced that a number of them are in business from purely philanthropic motives. What Mr. Merz has so ably described to-night is very different from what was

originally put forward by the power company promoters. Mr. Word-  
ingham.  
Their main idea at that time seemed to be to concentrate on one station. The diagram (Fig. 1) which Mr. Merz showed was very convincing, but unfortunately all the areas with which we have to deal have not a uniform distribution of load nor are they in squares. The present position of electricity supply is not, I think, so bad as he made out; many areas have this linking up in a more or less perfect degree. The linking up of the four squares that he showed was admirable, but I do not quite know where it is to stop—whether the whole country is to be linked up in that way, or one important area, or several important areas. By far the most successful power scheme owned by a company in this country is not a power scheme with a single station but one with numerous power stations, and it is that linking up of a number of stations to serve a comparatively small area which I believe is the secret of its success. Turning now to the scheme put forward by Mr. Williams, I would deprecate as strongly as possible Government interference with this sort of enterprise. Every scheme of the kind must ultimately depend on its being a financial success. I do not believe it to be possible for a Government department to run any trading concern on commercial lines—I refer to commercial concerns, not national concerns; and I say that advisedly. One of the essential elements of success in any scheme of this kind is the power of bargaining, and a Government department cannot bargain successfully in a commercial matter. If this cheap supply, which we are all agreed is necessary, is to be carried out, it can only be done by the very ablest men working unfettered. Every big Government department must be fettered by rules and regulations, without which it could not exist, and it must be fettered by other people being brought into the matter who have no intimate knowledge of what is at stake and who are unable to conduct the operations with the secrecy, and perhaps in some cases with the opportunism, which are necessary to the success of a commercial concern. Then again I would deprecate what has been said by other speakers of bringing all these various things under one control and establishing a Ministry. If Ministries are to be multiplied, the whole time of the community will be spent in receiving inspectors and making out returns.

Mr. W. L. MADGEN: I feel sure that Mr. Williams, in Mr.  
Madgen.  
describing the Ontario Hydro-Electric Commission, has given an honest reflection of what has been represented to him, but I must warn members against accepting that description as entirely accurate. I have had occasion in normal times to visit Canada with some frequency; I have some knowledge of the operations of that Commission in Ontario; and of all the public bodies I have come across I do not think I have met a more reprehensible one. If members conceive, for the moment, a Board of Trade that in some degree regulates the industry as our Board of Trade does here, that adjudicates on questions arising with supply undertakings, that is in charge of legislation affecting the industry, while at the same time that authority itself is a <sup>fully</sup> authority and able to encourage competition with ordinary supply authorities who have had to find money from time to time for their undertakings,—it will be realized that the effect has been most cruel. During the past 20 years or more in different parts of Canada, particularly perhaps in Ontario, electricity supply

Mr.  
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undertakings have been established with local money subscribed by enterprising people in those districts, and these small undertakings have struggled as some of our undertakings have struggled here. During the last few years, however, a public body has been established which not only can generate electricity itself but has other general powers in regard to the industry. To my mind there can be only one end to that sort of thing; it will crush out enterprise and the industry will suffer. As the number of technical officials increases, the consulting engineering department of the profession will decrease. If Mr. Williams takes the Ontario Hydro-Electric Commission as an augury of success for such a concern here, I think he is very greatly mistaken. It has the double function described by Mr. Highfield; it has the function not only of control but of operation. I agree with Mr. Highfield that if the body proposed by Mr. Williams was expressly divested of the function of operation it might prove very useful, once we have become more unanimous among ourselves upon the broad general principles which should govern the generation of electrical energy and its distribution in this country.

Mr. Roles.

Mr. T. ROLES: Mr. Merz has said that before such a scheme as that proposed by the author can be carried out the electrical profession must be agreed upon the general principle involved, namely, that of co-ordinating the control of the whole of the electrical generating stations in the country under one central authority, with the object, as far as possible, of generating electricity in the future in a comparatively small number of large and efficient stations, rather than in a large number of small stations as is the present practice. Mr. Merz also expressed the opinion that the electrical profession is not agreed upon this principle. I venture to suggest, on the other hand, that the profession as a whole is agreed upon it, and if every electricity supply engineer in the country were certain of being one of the six electrical managers mentioned by Mr. Williams, or of being given charge of one of the large generating works or areas described by him, he would not be afraid of saying so. But, as Mr. Williams has said, it is the human factor that counts. If a scheme such as Mr. Williams has described were introduced by the Government, in which not only the larger stations but also the smaller ones could be brought in, dependent more or less upon how those stations are being worked, I think there would be a general body of electrical opinion in favour of it. The majority of electricity supply undertakings, however, are in the hands of local authorities, and the latter are not likely to hand them over willingly, in view of all the time and money that have been spent on them, unless a just cause is shown. Electricity committees, for the most part, have not had the matter put before them for their consideration, the reason being that the engineers have not cared to broach the subject, because in many cases they have been afraid that it would adversely affect their personal interests. If the Institution could develop this scheme on such lines as would obtain the sympathy of electrical engineers, I think it would not be long before the electrical engineers obtained the sympathy of their committees, a good engineer usually being able to lead his committee where a technical question is involved. The interests of the engineers of small undertakings are well worth considering. It is marvellous what some engineers

have done with small undertakings, and the low costs they have already reached. Every credit is due to them for that, and if they were put in charge of bigger work they would in all probability do better still. I think it is time that the question were elevated from the plane of talk to that of action, and I consider the Institution, as the premier electrical body in this country, to be the one that should take it up.

The PRESIDENT: I regret that there is insufficient time Mr. Merz left this evening to enable me to take any real part in this discussion. Eleven years ago Mr. Merz convinced me and a great many others, after a Parliamentary Inquiry, what are the real factors in this business. Eleven years have gone by and we are still stumbling over the same ground. It is not that engineers do not recognize what is the right principle; it is the human factor. In many districts if a supply is offered in bulk, it does not matter how low a price is mentioned, the local engineer at once draws up a scheme showing that he can provide the supply for a less sum. He convinces his committee and he retains his job. Until we can get rid of this human factor it is of no use going to the Government, or setting up committees, or doing anything else. Some authority with sufficient power must be set up to deal with these people. After all, it is a matter of common sense. Engineers ought to realize that if the industry is to grow there is plenty of opportunity for all those who are of any use at all. They must recognize that there is an increasing demand for reliable men. Those who are incompetent, on the other hand, must go down, and we ought to help to push them down. There can be no doubt as to the importance of this scheme which must be put into operation. The real principle at the bottom of it all is the conservation of fuel. That is a national necessity, particularly in regard to the use of the fuel in such a way that we can obtain by-products for the chemical industry. Cheap power is important, but the conservation of fuel is of far greater importance. I should like to make one small correction with reference to a remark made earlier in the discussion. A previous speaker suggested that the price of electricity in London varied from 3d. to 8d. per unit. I do not know where he got the figures from. In London electricity is bought and sold at a commercial price, and it is possible to buy electrical energy in quantity in many districts at a fraction of one penny per unit. I only say that because London's electricity supply is always decried, and because if a wrong statement is repeated sufficiently often people begin to believe it. Electricity supply in London as compared with the Provinces is not in such a bad state as many people think. After the subject has been further discussed at the Local Centres, the Council will consider the views expressed.

Mr. J. W. MEARES (*communicated*): One of the main difficulties likely to arise in linking up districts for the purposes of bulk supply is that of wayleaves. Notwithstanding Mr. Merz's view that the experience of other countries is of no great value here, I think that a provision such as we have in India would be of great value in this matter. There the Government can confer upon an electric supply authority the powers which the telegraph authority has for placing lines and posts across private property without acquisition of land. Those powers have been extensively granted and used. In the case of under-

ground trunk mains the same procedure would be applicable. There was a sharp difference of opinion among the speakers at the meeting as to the policy of losing money for a time to gain the more later. To make such a policy possible at all it will be necessary to educate directors and committees, which is a slow process, and the enormous differences to be found in the cost of energy and its selling price show how necessary this education is. If pooling of interests and bulk supply could be managed all over the country, it would at once be possible to bring rates down in the majority of undertakings; but, on this side of the water, Trusts of this magnitude are not easily worked.

Mr. CHARLES BRIGHT, F.R.S.E. (*communicated*): I think Mr. Wordingham might have usefully extended his remarks regarding the difference between State work of a national defence character and otherwise. In my view a definite line should be drawn between anything concerning the nation as a whole and that which only concerns a certain section or class. I would urge, in fact, that the dividing line between what can rightly be made a subject of general taxation and what cannot should be on this principle. Thus, in services secured by electrical means, whereas inter-imperial telegraphic communication intimately concerns the security and welfare of the nation and Empire, we have here a subject suitably adapted to public taxation, yet the same cannot be said in the case of light, or power supply by any particular means.

Mr. E. T. WILLIAMS (*communicated*): In reply to Mr. Merz, I should like to make it quite clear that my proposals were addressed to electrical engineers. My intention is not that we should seek the establishment of an Electricity Board first and then proceed to educate engineers to its advantages, but that the presentation of our proposals to Parliament made be subsequent to and following upon the support of the profession in general and of the electricity supply industries in particular. Without this I believe my scheme would hardly secure success, but with it I think our cause is so strong as to command attention and compel achievement. The paper does not state that the technical and financial aspects of the subject are simple—they are far from being so—but that "the basis of organization," which may be taken to include the human factor and the co-ordination of various interests, is the most difficult.

Mr. Chattock wishes that I had laid more emphasis on the justification for such a scheme as that advocated in the paper. I am afraid the cutting down of the original paper to its present dimensions, in order to form a basis for a general discussion, is responsible for this and for other points mentioned by various members in the discussion. Mr. Chattock raises a very large issue in his proposal that no return should be expected during the early years on the money spent in carrying out the scheme. I take it Mr. Chattock refers to the money spent by the proposed Board and not to that which might be expended by municipalities or companies. This proposal goes down to the fundamental principles of political economy. The Continental school largely accepts such proposals as being sound, since the trade of the country as a whole would be benefited; and Germany in particular has followed this line of argument with success. The British policy, however, has been different, and, with the

exception of a subsidy to certain steamship lines, the principle followed generally has been that each development must make its own progress without State support. The chief objection to Mr. Chattock's proposal to replace small generating stations by a bulk supply at once, is that it would raise powerful opponents against our scheme and thus prevent its fruition or defer it indefinitely.

I should like to correct an impression held by Mr. Highfield and other speakers that because I have brought out the thought of trading for the public good I propose to do it at a sacrifice to vested interests, whether of capitalists or of engineers. This is not my intention. The crux of the whole position lies in the fact that by working together we can cheapen the cost of electricity and so create a high demand. The result will be that not only will the public benefit but the capitalist and the engineer will also participate in the advantages that will follow. It is our duty to the interests we represent, and to ourselves, that we should ensure this being the case in any scheme we may advocate. I think the paper makes it clear that there is no tendency to belittle our past and present achievements in electricity supply. With the legislative difficulties that have to be overcome, what has been attained is truly remarkable. Apart, however, from the few exceptions of which the North-East coast is only one example, can we say that the position of the industry is satisfactory, considered from the standpoint of what it might be? Does not the very success of the North-East coast power supply heighten the contrast with other areas, and yet augur well for electricity supply in Great Britain if we can organize our resources and treat the country as a whole without unduly interfering with the separate enterprises? Can we say that the position is satisfactory while vast areas have no supply of electricity at all and while in other areas the undertakings are small and the price of electricity very high? Mr. Highfield raises the very important and difficult subject of the same Board having controlling as well as operating powers. This has been and is one of the real difficulties to be considered. If we could be assured that the requirements of the country could be met without the Board having operating powers, I would readily agree that it should only be a controlling Board. Again, if this question of dual powers became a stumbling block to the profession reaching an agreement, I would suggest that rather than have no Board, or co-ordinated control at all, it would be better to give way on the operating question and carry through as a united profession the proposal for an Electricity Board with controlling powers only. That would be a very great advance on our present position. Before we do this, however, let us consider whether the interests of present undertakers cannot be properly safeguarded in the Act of Parliament by which the Board would be created and which would form its charter. I believe this can be done without great difficulty and the Board prevented from operating in competition with any existing undertaking in that undertaking's area. If any existing or future undertaking is operating satisfactorily in its specified area, the Board would have no power to compete nor would there be anything gained by its doing so. If, however, any undertakers were misusing or abusing its powers it would be the Board's duty to represent the matter to Parliament with a view to having the powers transferred to another

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undertaker or to the Board itself. If the Board had no operating powers would it not be a very serious loss to the present undertakers? For example, the interconnecting network between power stations, or the provision and maintenance of certain bulk-supply mains might readily and economically be dealt with by the Board. Then there is the question of a supply in agricultural districts; are they to be left without a supply if no undertaker can be found to supply them? Again, take the important national question of the conservation of fuel; if present undertakers are not prepared to lead the way with experiments of gas-fired boilers and the production of by-products on a large scale, is the Board's power to be restricted to prevent its acting as a pioneer? It is also readily conceivable that in some cases the Board might act as co-operators (with companies or municipalities) to the advantage of all parties, for with their powers of raising money at low rates of interest they could bring important financial support to play in assisting development. I would therefore urge that before we summarily dismiss the question of the Board's having operating as well as controlling powers, we should carefully investigate and consider whether the difficulty cannot be overcome by fully safeguarding the interests of present or future undertakers without depriving the Board of powers which would be very valuable to the industry but might be exceedingly difficult to obtain once the Board is established.

The points raised by Mr. Woodhouse and Mr. Wordingham have been mainly dealt with in the replies to other speakers.

Mr. Roles, speaking of a large and important section of the profession who will be a controlling factor in the success or failure of the scheme, admits that there is little doubt in the minds of most electrical engineers as to what

ought to be done. I have very great sympathy with, and respect for, the interests to which Mr. Roles refers and for his candid statement of the facts. I welcome his suggestion of endeavouring to bring into the scheme those smaller stations, which would not form part of the ultimate scheme, in order to avoid the opposition of the electrical engineers and municipal committees or supply companies controlling them. I propose that this might be done in the following manner. Assuming that a number of small towns in any district will be supplied by one large station in the final scheme, there is no reason why the necessary capital should not be subscribed by these town councils or companies, and the large stations built and worked jointly by the electrical engineers of the towns concerned. Thus, during the transition period as the small stations were gradually changing from generating stations to transforming and distributing centres, the large station would be growing rapidly and the borough, or companies', electrical engineers would be transferring their generating interests from one small station to one large joint station. I should very much like to see the power companies brought into such joint action, and this is where I consider the electrical engineer managers of the Electricity Board would be very valuable in acting as an intermediary or independent centre for co-ordinating the common interests of any district and enabling such joint schemes to be brought about.

The President has summed up the situation by pointing out that the success of this or any other scheme depends on the human factor. If we could only get together and bring common sense to bear on the problem we should soon make some progress. His statement that the Council will consider the views expressed during the discussion in London and at the local centres will be welcomed by all.

#### MANCHESTER LOCAL SECTION, 18 APRIL, 1916.

Mr.  
Robertson.

Mr. J. A. ROBERTSON: The present position of electricity supply in this country calls for serious and careful consideration, in view of the steps which will have to be taken at the end of the war to re-organize and re-establish our national industries. The restrictions placed by the Local Government Board last year on new capital expenditure, coupled with the largely increased output of energy for War munition purposes, have reduced the reserve plant capacity in most central stations to a margin which would have been considered totally inadequate in normal times. The problem of how to utilize to the very best advantage the existing capacity of plant in central stations is therefore one that should receive the immediate and careful attention of all interested in electricity supply. The most serious difficulty with which central stations have had to cope during the last year has been the high price and the shortage of fuel supplies. The position was so serious last year as to call for Government legislation, and the Prices of Coal (Limitation) Act was passed in July 1915. While the Act conferred an immediate benefit in restricting the inflated prices which were then demanded, I am afraid that the intention of the Act is not being fulfilled at present and that large quantities of coal are being sold at prices considerably above the maximum

increase of 4s. per ton. The existing conditions call for thorough investigation, and if found necessary the Act should be amended to carry out what was undoubtedly the intention of Parliament in passing it. Indirectly the difficulties under which central stations have been operating will do much good. Manufacturers who are still generating from private plants or using steam or gas power have found their power costs increasing by 30 to 40 per cent, while the central station consumer has not been called upon to pay more than 10 or 15 per cent increase in the charges for electrical energy. We have, therefore, the unique position of manufacturers applying for power supplies who were previously convinced that they could produce more cheaply with their own plants, while central station engineers are refusing applications which no amount of canvassing could formerly obtain. The ultimate effect is bound to be beneficial to the electrical industry, and the time is therefore opportune to consider steps for improving and strengthening our position after the War.

In Mr. Williams' paper we have Dr. Ferranti's idea for centralizing electricity supply put in the form of a concrete proposal. Mr. Williams believes that the time has arrived when a national scheme of bulk supply from

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large central stations might be introduced which would gradually supersede the inefficient and, in some cases, obsolete stations now in operation. The bulk-supply undertaking would be owned and operated by the State through a Central Board. The Board is to consist of 11 members, six being engineers, each responsible for electricity supply in one of the six districts into which the country is to be divided for supply purposes. The Board would be empowered to erect and build large generating stations and to supply in bulk to existing authorities. Incidentally the Board would also take over the functions now exercised by the Local Government Board, the Board of Trade, and the Home Office. All central station engineers will agree that centralization is desirable, but there are certain stages of development to be passed and difficulties to be overcome which are overlooked in the paper. The technical difficulties cannot be set aside, particularly the differences in frequencies in various districts. For instance, while the large system at Newcastle has a 40-cycle supply, most Yorkshire and Lancashire towns have adopted 50 cycles. In Birmingham 50 cycles is a standard, but the South Wales Power Company's supply is at 25 cycles, although the supply in Cardiff is at 50 cycles. In the Glasgow district both the power company and the Corporation have adopted 25 cycles. Everyone will also agree that the present Government control of electricity undertakings by three departments is unsatisfactory, but to set up a Board which will operate electrical undertakings on such a large scale, and to give the Board powers now exercised by three Government departments, is a proposal which is open to severe criticism. I think also that to place the control of a district comprising say the Midlands or the North-West of England in the hands of one engineer manager will not commend itself either to engineers or local authorities. It will be noted that the scheme does not propose to interfere with existing undertakings, but simply to set up a trading concern selling electricity in bulk. The power companies have been trying to do this for many years and have made little headway, because they found in most cases that bulk supply cannot be delivered to central stations at a price sufficiently low to pay the standing charges on the necessary cables, converting and transforming plant, and also the standing charges on the superseded generating plant. Again, the Central Board would have no powers to compel a local authority to shut down its generating station, or to fix the price which the existing authorities are to charge for current. A local authority might therefore continue to operate its own plant and even to pay its extensions out of revenue, or it could purchase current from the State system in bulk, and re-sell it at prices which were deliberately fixed high to ensure large profits for the benefit of the district rates. In either case the object of a bulk-supply scheme, *i.e.* the provision of cheaper electricity for all industrial and domestic purposes, would be defeated. The principle of State ownership of public utilities has provoked much controversy, and the addition of electricity to the list will prove a further bone of contention. On the one hand it will be argued that the State can provide cheaper capital and that the business will be conducted for the public good instead of for private interests. On the other hand it will be charged that State administration is lax and incompetent compared with that of a private company, and that com-

mercial development is often subordinated to political considerations. If it is necessary to centralize electricity generation on national lines, the only alternative to State ownership appears to be ownership and operation by a private company under State control, or State ownership with operation by a private company on the lines recommended to the London County Council in Messrs. Merz & McLellan's report. These questions will require ample consideration, and care must be taken that in profiting by one mistake we do not make another by rushing to the other extreme. My point is that the present is not an opportune time for central station engineers to discuss questions of this magnitude. State ownership may be the ultimate solution of the all-electric problem, but we shall be faced with an enormous difficulty probably in a few months, or at most in a year or two, to meet the demand for a cheap power supply, which is vitally essential for increasing the productive capacity of our factories after the War. Our task for the present is to ascertain what steps can be taken to utilize our existing facilities to the fullest extent, taking care only to make extensions or adopt methods which can be worked in as part of a larger scheme when the time is ripe for it. The policy of linking up existing undertakings, which has been adopted in one or two London boroughs, ought, I think, to be seriously considered. If we look at Garcke's map of electrical undertakings in Great Britain, we shall find that the country divides itself for electrical purposes into 10 or 12 areas. These areas all represent the important manufacturing districts, and to a large extent the coal mining districts of the country. Starting with London as the first and largest area, there is an area, which I shall call No. 2, around Birmingham. South Wales is No. 3. The Midlands might be divided into two areas, one (No. 4) including the Sheffield district, and the other (No. 5) taking in Derby, Nottingham, and Leicester, with the smaller towns surrounding them. Lancashire would provide two areas, the first and largest being the Manchester district (No. 6), and the other (No. 7) the Liverpool district. The central area of Yorkshire would be No. 8, and the North-East district, including the Newcastle Electric Supply Company's supply area, would be No. 9 area. Scotland would be divided into two areas, one taking the industrial area (No. 10) for about 15 miles round Glasgow, and the other, which would couple up Edinburgh and several small stations in the neighbourhood, would be No. 11. Each of these districts would provide an area of supply in which the existing central stations could be linked up at a moderate cost for supply purposes. Later on, when times are normal, it would be a simple matter to supply the network thus formed from one or two large modern stations. About 220 generating stations out of a total of 364 in the whole country would be included in those areas. Most of the remainder are in residential districts and it would not be commercially profitable to connect them to any system of high-tension networks. As an instance of what linking up might do, the Manchester district is a striking example. There are situated within the Manchester area 15 generating stations with an aggregate generating capacity of 170,000 kw. Nine of these stations are generating 3-phase energy at 50 cycles, and there are no technical difficulties to prevent them being linked up immediately. The result would be an enormous benefit all round. In place of each station requiring to

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maintain a complete equipment of reserve plant, the stations would act as a reserve to each other, and the aggregate demand on the whole of the stations could be safely increased by at least 30 to 40 per cent. The risk of interruption would be greatly diminished, and by running the most efficient plant on the system continuously at full load, leaving the less efficient plant for peak loads, the cost of operation would be substantially reduced. A number of stations could be shut down entirely at week-ends. The smaller generating stations with continuous-current plant would gradually install transforming and converting plant and so receive the benefit of the combination. This linking-up would offer at least a partial solution and serve as a stepping stone to a bigger centralization scheme. There appears to be no insurmountable difficulty in putting this scheme into operation. Hitherto the chief obstacle to any co-operation between existing authorities has been local jealousy, but if machinery were put in motion to combine these authorities for a common object, this jealousy, which is largely due to misunderstanding, would probably disappear. I would propose the formation of Joint Boards for each district, such Boards consisting of representatives elected by the supply authorities, together with a certain number of independent members appointed, say, from the local manufacturers, who after all are the parties most interested in the question of cheap power supply. With regard to the cost of linking up, this could be borne by the local authorities in proportions which could be determined either by the use made of the system, *i.e.* the standing charges on the capital cost could be allocated in terms of the electrical energy purchased by the local authorities from each other, or, considering the general all-round advantage of such a scheme, there would be no serious injustice if the cost were borne in equal proportions by each of the undertakings. As the Joint Board would require to raise capital, Parliamentary powers would be necessary, and these powers might be limited at first to the raising of capital for the consolidation of existing undertakings. If, as I believe, however, the system works satisfactorily, the powers might be enlarged later to include the extension of existing undertakings and the building of new stations. By this means we should obtain uniformity in administration; and other benefits, such as standardization of rates for supply, would naturally follow. It is not suggested that this proposal would provide a complete solution of the problem, but it is at least more attainable than any nationalizing scheme could possibly be at this stage, it could be put into operation with the minimum of cost, and what is more important at present, with the minimum delay. I thoroughly agree with the suggestion that the powers now vested in the Local Government Board, the Board of Trade, and the Home Office should be combined in a Central Electricity Board. This Board, which should be mainly composed of electrical engineering experts, would be the sanctioning authority for loans, and would therefore be able to exercise technical supervision over the proposals of the district Boards. There is another question, closely bound up with the centralization of electricity supply, which unless dealt with on national lines will prove a serious hindrance to the object we are aiming at. Although poorer in some natural resources than other countries, we have an abundant supply of high quality coal. The only possible competitor is oil fuel, which may be left out of

account while we are dependent on foreign markets for our supplies, and in any case all the available supply will be required for many years for Naval and mercantile marine purposes, where it offers special advantages. We are, therefore, absolutely dependent on the supply of coal for that production of power which is essential to our industrial needs. Coal-getting and coal-distribution are outstanding examples of our haphazard methods in dealing with matters of vital importance. The colliery owner is left free to extract the coal, to sell it to the highest bidder, even though he be the agent of a foreign Government not too friendly to this country. There is no attempt to grade or classify coal from particular districts for industrial purposes. Prices vary within wide limits, and at one time we are threatened with interruption of supplies through workmen's strikes, while at another time stocks are held up in order to inflate prices artificially. In past years competition was the consumer's only protection, but with the demand overtaking the supply we can hardly blame the proprietors for eliminating competition and so increasing their profits. I would suggest that the time has arrived when a Commission should be appointed by the Government to report on our national supply of fuel, with the object of utilizing it to the best advantage for the various chemical, metallurgical, and other purposes for which it is required. The question of transport should also be dealt with, so that we should not witness the anomaly of coals being shipped from Newcastle to Manchester district, whilst collieries within a 20-mile radius of Manchester are actually sending consignments of coal to Newcastle for export. The Limitation of Prices Act will require to be strengthened and compulsory arbitration introduced to prevent an interruption of coal supplies through strikes of workmen. To avoid such strikes, some form of profit-sharing might be established which would give the worker a direct interest in the concern for which he works. These proposals may seem somewhat daring, but if we are to make good the wastage caused by the War and to retain our commercial supremacy the problem must be dealt with on broad lines. Our aim should be to convert our natural resources, fuel, and labour, into power, light, and heat, so as to achieve the highest individual and national efficiency. If the War causes us to scrap our old methods and to re-organize existing systems with the view of attaining higher standards, the enormous sacrifices which it has entailed will not have been in vain. In the meantime, while we are expending all our skill and energy in assisting to bring the War to a successful conclusion, let us also at the same time commence to set our house in order and utilize our existing powers so that electricity may take its proper share in the re-organization of industry, which will inevitably take place when peace returns.

Mr. J. S. HIGHFIELD: Mr. Robertson has dealt with the fuel difficulty and seems to contemplate that after the War the price of coal will remain at a very high figure. Speaking solely as a supplier of electrical energy I hope it will, because our business as public suppliers of energy is to save coal. In fact one of the main reasons why electric supply undertakings are successful commercial ventures is that we produce the same result with less than half the weight of coal used by the individual manufacturers. The higher the price of coal the easier it is for us to carry on our business. Of course the price to the manufacturer for

electricity will be higher according to the cost of coal, but if he pays 20s. a ton he will not be able to waste coal in the same way that he can if he only pays 8s. Therefore if we are to contemplate higher prices after the War—and very likely Mr. Robertson is right—so much the better for public electricity supply. Mr. Williams in his paper rather discarded the history of industry, but I consider the past history of an industry to be always a most useful guide, and if we neglect history we are, as it were, throwing away one of the sheet anchors which ought to hold us to the path of progress. I do not want to look back too far, but I should like members to consider how the concessions granted for public electricity supply differ from, say, those of the railways and the great gas undertakings. The Railway Acts granted permanent concessions to the companies, subject to protection for the users both for goods and passenger service, to run railways in particular areas; when they wanted to extend those areas they had to get additional powers. The result is that we have established the great railways of England, and I suppose that nowhere in the world are there better railways. In fact, the creation of the railway systems of this country is one of the most wonderful pieces of commercial work. Those systems, to a certain extent, entered into competition with each other; and this, although it resulted in some waste and unnecessary duplication of lines and stations, had the advantage of bringing a great many more men into the business and a great deal more money than would otherwise have been the case, so that the rate of development was more rapid. The history of the gas undertakings is somewhat similar, except that the municipalities themselves in very many cases put up their own gas-works. They, too, had permanent concessions; they were not subject to compulsory purchase and the customers were protected, as in the case of the railway companies, but by a different method, by what is known as the sliding scale, which makes it incumbent upon the company to reduce the price charged to its customers before it can pay a higher dividend. Although there is some objection to the sliding scale, which could be improved in the light of experience, still on the whole this method has worked uncommonly well. In connection with electricity supply the fatal mistake was made, so far as the companies were concerned, of making the concessions terminable. I altogether disagree with Mr. Robertson's suggestion that if any further concessions are granted to companies and private enterprise they should be terminable. This is where history guides. The first Electric Lighting Act was in 1882 and the concessions were for 21 years. What was the result? Not a shilling could be raised for carrying out any electricity supply schemes, and six valuable years were wasted before a public supply on any extensive scale could be introduced, owing to that very stupid Act of Parliament. It is a pitiful example of politics hampering progress. In 1888 the term was extended to 42 years, and about that date the existing electric lighting companies were formed. The 42 years' term is now drawing to a close—there are only 15 or 16 years to run—and very soon we shall get this difficulty, that these companies cannot raise capital for so short a period, and they will not like to invest their reserve funds too freely in the business because they do not know whether their undertakings will

be bought or if they are bought how much they will get for them. Nothing in our business calls so loudly for remedy. I have therefore no hesitation in saying that legislation which grants a terminable concession, with an uncertain price at the end of the time, is fatal to the successful conduct of a commercial enterprise. When the Power Companies Acts were passed about the year 1900 that fault in the original legislation was realized and these Acts did not contain the compulsory purchase clause. The power companies are like the railway companies and gas companies, non-purchasable concessions. I look forward, therefore, to considerable success for the electric power companies, in spite of the fact that the large towns were generally kept out of their areas except in the case of the Cornwall and South Wales Power Companies. It is gratifying to see that those who ventured their money in power companies, which for years worked without any profit at all, are now obtaining some sort of return and can look forward to a hopeful future. I think we ought to consider the present position and I am very glad Mr. Robertson dealt with the matter in such a practical way, because he arrived at a conclusion and had a definite recommendation to make. Take the present position, which we cannot illustrate better than by the Manchester district. Here we have a large number of municipalities, some very large, owning their own power plants and supplying the public at reasonable prices. If I wanted to erect an engineering shop in almost any town in Lancashire I should be able to get electric power supply at approximately the same price whether it was a small town or a large one. And it would not be a case of going to the engineer and asking for a supply; he would wait on me and insist upon my taking the supply. There is no question that the electrification of England under powers hitherto created has been most successfully carried out, and I agree with every word Mr. Robertson said about the work which municipal bodies, large and small, have done. Taking it all round, the engineering work has been well done, and on the whole the undertakings are a commercial success. All this is true, but it may be necessary and advisable, in order to make further progress, to establish such Boards as Mr. Robertson has suggested. I should like to call them Local Boards, to distinguish them from the larger Board Mr. Williams wants to establish. Even without forming these Boards, however, a great deal might be done. We have in this part of Lancashire, besides these large and medium-sized municipal power stations, the Lancashire Electric Power Company which, I think, deals with the balance of the area or nearly so. Between them surely something more can be done in regard to what is known as linking up, so that the small stations shall not be unnecessarily extended. It is very easy to decide when the small station has got to the limit of its capacity, provided that we know at what price energy can be purchased from other undertakings, and in my opinion a great deal can be done in Lancashire and in many other parts of the country without any further powers at all. I think the electrical industry has suffered in this matter from professional jealousy. There has not been that assistance given by the manager of the small undertaking to the manager of a large one—and vice versa—which would have made inter-connection possible. The municipalities have been remiss

Mr.  
Highfield.

in this respect. Difficulties have often been due to the action of the managers and of the authorities who control the works, and I think much could be done if human nature could be somewhat altered. I agree that it is a large job and I have not a great belief in Government control, because we are not going to alter human nature by Act of Parliament. The War, to my mind, is going to do much for us; it is making us all see that the success of our neighbour is in a very great measure our own success; if we see our neighbour getting on, that probably means that he is in a better position to help us. With regard to the appointment of local Boards, I take it Mr. Robertson wants a Board something similar to the Water Board in London. In that case there was a large number of private companies, and the Water Board was formed of members appointed by the different county councils and municipalities. It bought up the whole of the companies' undertakings, and it now supplies water to the whole of London. The difficulty about a body of that kind is that it is responsible to nobody. It is not like the Board of a company since the shareholders are always there to keep it in order, nor again is it like a municipality where the ratepayers fulfil the same function. Some of the matters Mr. Robertson will have to think about are: How is that body going to be adequately controlled, by whom is it to be elected, and to whom is it to be responsible? I am not objecting to the principle at all, but I am pointing out the possible defects such bodies suffer from through too little control. Mr. Williams' Board is a much more serious matter. His Board is to be formed, as I understand it, as a Government department and is to have two functions. One function is the power to go to the manager of a small station and say: "Your small station is of no use; it ought to be made into a sub-station, and you must take a bulk supply." That is all very well as far as it goes, but the Board would have the further power to say: "You must take the bulk supply from us." Now I consider a combination of the judicial function and the trading function to be not at all correct. If the Board is going to be judicial it must not also have trading powers. Therefore I do not much like Mr. Williams' Board. With regard to the actual merit of linking up stations, in certain cases where two or three big stations work on similar systems, and within a reasonable distance, there can be no doubt whatever that it pays to link up those stations, because instead of putting down three small sets, or comparatively small sets, one in each of the three stations, we can put down one large set, equal in size to the above three, in one station. That is without question the right principle on which to proceed. But, solely with the object of providing matter for further thought, I should like to point out this. I have to do with a very great number of very small stations and we supply from many of those stations at prices similar to those offered by any large undertaking, the figure for a long-hour steady load being about 3d. a unit. One of those works has a maximum load of 300 kw. and another of 700 kw., and yet they are able to supply power at that very low price and, at the same time, earn from 6 to 8 per cent on the capital outlay. The fact that small works of that kind can be so successfully run, not only from the point of view of the shareholder but also from that of the consumer, provides food for reflection. There is one point which has not been touched upon

to-night, but I hope it will be, and that is the question of finance and profits. This was discussed in London and one of the speakers suggested that we should work for the public good—I mean by "we" electricity supply authorities—and not earn profits. I do not hold with that at all. I do not see why the supplier of electricity has not just as much right to a profit as the supplier of gas or any other commodity. A municipality must clearly cover its interest and sinking-fund charges, and it ought to have a margin over that amount. I do not care what is done with the margin, but in this connection I suggest that a portion, at any rate, of the profit might be set aside for experimental purposes, particularly in the better use of fuel, the most important of all our problems. I consider it to be essential that the electric supply business should be self-supporting, that it should not want rate aid or State aid, and that it ought to make adequate profits and so be in a position to raise capital on its own credit.

Alderman W. WALKER: The first claim Mr. Williams makes in favour of the adoption of his scheme is that of cheap sites. Personally I place little or no value upon the question of the price of a site when we are going to put down a station which is likely to cost from one to two million pounds. What does it matter whether the site is going to cost £500 or £1000 an acre for some 20 or 30 acres? It is quite immaterial; the sinking fund and interest on that amount is so small that it can be easily offset by a slight advantage in the water supply, or by an additional fraction of a penny on the carriage of coal. An adequate supply of fuel, drawn from more than one coal-field, combined of course with a plentiful supply of condensing water, are the main considerations. The question of fuel is becoming of greater importance to those connected with power stations than ever it has been in the past, and the results of the Coal Limitation (Prices) Act, which was supposed to be in the interests of the purchaser of coal, have proved disappointing. It does not do what it was drafted to do, and it has completely failed to benefit the large power stations. As to the date which was to govern the price, we all supposed it to mean, as no doubt those who discussed it in Parliament intended it to do, that it was the price in existing contracts, but we found out as soon as the Bill passed that the coal dealers were able to get legal opinion to the effect that it was not 4s. on the price of the then running contracts but on the contracts 12 months previous to that, which was going back two years. The words bore that construction and we have had to pay on that basis. Its attempted protection of the consumer has been futile. What is the use of going to a coal contractor and telling him, "you cannot charge me more than a certain amount," if he tells you he has not got coal to deliver and you have to go to somebody with whom you have not before had a contract and make new terms with him? We have paid at Manchester more than double the maximum increase supposed to be allowed by the Act. We are in the position of having to run trucks to Newcastle-on-Tyne to bring coal to our Stuart-street station, and it is most unsatisfactory, considering the present congested state of our railways, that such conditions should prevail. The desirability of linking up is, I think, universally admitted. It would be said that, in principle, the linking up of the stations within the areas described by Mr. Robertson

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would be a good thing for the community which they serve, but it is when we come to the details that a new factor enters, namely, the human element. When we have to deal with public representatives in the case of municipal electricity committees, with directors in that of companies, and with the professional and technical staffs, we immediately find that each of them takes a conflicting view as to which is the main concern and who the most important person. I was glad to find that Mr. Robertson was so far able to get over that particular factor by mentioning Manchester in the area for Lancashire, and I agree with him that on those lines something could be done. We are handicapped by the present system of having to go to Parliament, with its out-of-date procedure, for permission before a step can be taken in the direction of improving the conditions in a given area. Just outside a city there may be areas which have not been developed electrically, and those who have the controlling influence—I am speaking of the public representatives and not the technical staffs—do not seem to desire to do anything. Yet, whenever there is an attempt to introduce a scheme to put the would-be consumer in the position of having a full and adequate supply of electrical power, the public bodies are able to bring such pressure to bear, on the ground of local sentiment, that they can get the scheme rejected by a Parliamentary committee which does not wish to bring itself into conflict with local leaders on a question which does not greatly interest it. I think there ought to be some body to whom an appeal could be made, which would consider these questions solely on their technical merits and not with sentimental or political motives. I, for one, should heartily welcome the formation of a Board constituted on the lines mentioned by Mr. Williams and Mr. Robertson, and one that would have the power to control the areas over which it is placed; and for that purpose I should certainly accept Mr. Robertson's geographical areas. I am sure that in localities such as those he referred to, we could procure a Board which would have a clear knowledge of the likely development of the areas, the wants of the commercial community, and which would be able to devise an adequate scheme to meet the case. Mr. Highfield mentioned two small stations under his control which were able to supply electrical energy at a price as low as that of larger concerns. I wonder whether Mr. Highfield disclosed the whole of the case. It is quite possible that a small station, under special conditions, could supply an adjoining firm from the busbars at an extremely low rate, but when we have a large municipal undertaking which, under statutory obligations, has to be in a position to supply every would-be user under all conditions, then of course it is difficult to quote a price to every consumer which shall not be open to criticism. I think, however, taking it generally, it can be assumed that the figures published each month in the *Electrical Times* prove that the very large stations operating with large units of plant are more than justified, and that an increase in the number of stations of such capacity would be best able to meet the industrial demands that are likely to follow after the war. I hope the outcome of this discussion, and the one in London, will be that the Institution, co-operating with the outside industrial and engineering organizations,

Alderman  
Walker.

will be able to bring such pressure to bear on the Government that the matter will be placed, not in the hands of a Parliamentary committee—to my mind nothing would ever come of that—but in the hands of a body, created after consultation with the supply authorities, the technical heads, and the power consumers, which will make the necessary inquiries and put the proposals of Mr. Williams and Mr. Robertson into a concrete form. Organization is necessary, and at no time in our history have we been so prepared to receive suggestions for great advancements as we are to-day under the conditions of existing war.

Mr.  
McKenzie.

Mr. A. E. MCKENZIE: I will deal first of all with the Coal Limitation Act. I am sure most of the engineers in this room will agree that this Act is of very little service to municipalities in reducing the price of fuel. In Manchester last winter, owing to shortage of coal, we were faced with the prospect of having to shut down many of our large power consumers engaged on munition work, and it was impossible to get any assistance from the Government. Although we had bought more than sufficient for our requirements we found it necessary, at very short notice, to go to Newcastle to make further purchases of coal to continue the output from our stations. Then we were faced with another difficulty. Although we were able to purchase as much coal as we required at Newcastle, the North-Eastern Railway Company would not permit any of their trucks to come on to another railway, so that although we had bought the coal we could not possibly get it through to Manchester, even with the assistance of the Government, and we had eventually to buy 200 trucks to convey it to Manchester. I am just mentioning this to show that municipalities are not always behindhand, as some people think, in looking after the needs of their customers. With regard to the price of coal, I agree with Mr. Highfield that high prices are not altogether unfavourable to the electrical undertakings of this country. In Manchester, for instance, the price of gas has been increased approximately 24 per cent in the last 12 months, as against an increase in price of from 10 to 15 per cent for electricity. If I understand Mr. Robertson correctly, he suggested that the proposed new Board should fix the selling prices. I am afraid that would involve very considerable difficulty, because each municipality has its own ideas as to the amount of rate aid that the electricity department should contribute. The Manchester Electricity Department has for some years paid over the sum of £30,000 per annum towards the relief of the rates, which sum is approximately 1 per cent on the capital outlay. If it were proposed that the Department should be State controlled, I feel sure the inhabitants of the city would present great opposition to the scheme, unless this rate aid were to be continued. On the question of the linking up of stations I think we shall all agree that very considerable economies would be effected if that were done. It is absurd to think that municipal boundaries should be insurmountable barriers against such a scheme; also professional jealousy enters into the question. The engineers and chairmen of committees of small undertakings do not seem prepared to merge their individualities into the large undertakings. With reference to the question of whether any further local powers are necessary to accomplish the linking up of stations in the various districts as proposed by Mr.

Robertson, I do not think so, and I understand it has been already done in several London boroughs with very great saving. I am of opinion that in Lancashire it could be very easily arranged by the engineers of the various undertakings, together with the chairmen and vice-chairmen of their committees. If that could be done, a great step forward would have been made and good would undoubtedly result. It seems absurd, to my mind, that in the Manchester area there should be 15 stations supplying the needs of the district when three or four stations would do the work very much more cheaply. I am not inclined to agree with Mr. Highfield when he states that he could go to any town in Lancashire and get practically the same price per unit for the same load. I do not think he would find that to be the case to-day, even if it were so when he was resident in Lancashire many years ago. The average price per unit obtained in Manchester gives the denial to that statement. I agree with Alderman Walker that the cost of a site for a large generating station need not be very carefully considered. The facilities one site affords may far outweigh any slight difference in cost per acre there might be when compared with others. I suggest that the time is not ripe at present for the formation of such a Board as that outlined by Mr. Williams, but I think some scheme similar to that proposed by Mr. Robertson should be considered, and no doubt it would meet with the support of most of the members of the Institution.

Mr. S. J. WATSON: This subject is one of the most important we, as an Institution, have to consider. I have been particularly interested in the references made by Mr. Robertson and Mr. Williams to the question of Joint Boards. As other speakers have mentioned, the creation of Joint Boards is not in itself a novelty; we have already, in certain districts, examples of them in the carrying on of important public works such as water supply, sewage, and hospitals, and there is also the case of the Stalybridge Joint Electricity and Tramway Board. So that, as a means of operating in a district, such a principle has already been established. One of the most difficult problems to settle in connection with large Electricity Boards would be that of finance, and here let me say that if the supply is going to be developed to the very large extent which we expect it will be in the future, I feel that something more than municipal control is needed. In my view the capital necessary to carry out the work of such a Board should be found partly by municipal authorities and partly by private enterprise. Members of the Board would be elected to represent the various financial interests, and in this way we should obtain good results. Such a Board would be less open to criticism than if it consisted only of local representatives, and at the same time it would be more "alive" than we should get by any other means. If such Boards were formed in areas similar to that of Manchester we should possibly have representatives from all the larger towns possessing generating stations, and they, together with the representatives of private financial interests, would direct the operations of the supply undertaking over the whole area. We may even go further than this and appoint representatives from the local Boards to a Central Control Board in London which should be possessed of very wide powers. The chairman of such a Board might occupy a position similar to that of the Permanent Secretaries of some of the existing Government

departments, and it would be the duty of the Central Board to make representation, through the Permanent Secretary, to Parliament in connection with any electricity schemes which might be presented. Not the least important matter which such a Board would have to deal with would be the conservation of our coal supplies. It would have power to advise against the establishment of any further small generating stations, and as to the advisability of existing stations either being continued or forced to take a supply from some of the larger undertakings in the district. I have been interested in the remarks of Alderman Walker regarding the formation of a Joint Board in this area, and one of the first points that occurred to me was: What would Manchester have to say if they were approached by a number of small local authorities in the immediate locality? I think they would ask themselves in the first place: "What have we to gain by going into a Joint Board made up of these small surrounding towns?" and as there would be nothing to gain they would be inclined to leave the small towns to carry on on their own lines. Manchester itself would have very little to gain, because it would far outweigh in size, and in every other way, the undertakings immediately surrounding it. Some five or six years ago, in my address as Chairman of this Local Section,\* I went very carefully into what such a scheme would mean in the Manchester district, and although I may not have the figures quite correctly, I believe the position I arrived at was this. If all the supply undertakings within an 8- or 10-mile radius of the city were coupled up by means of trunk mains it would cost somewhere about £150,000, but there would be set at liberty for use spare plant to the value of approximately half a million of money. In normal times each undertaking provides spare plant to the extent of something like 33½ per cent, which represents in the aggregate an enormous amount of money absolutely locked up. If that money could be employed profitably it would not only strengthen our financial position but it would enable the industries in the area to be supplied at less cost than is at present possible. With regard to the establishment of large super-stations, to my mind there must be a limit beyond which a power station cannot become a practical problem, principally because of the enormous responsibilities which in the future will rest upon the supply authority operating these huge stations. In our large manufacturing towns the power used amounts to one-half to three-quarters of a horse-power per head of population. If in such an area as Manchester a serious accident were to occur at one of these super-stations, the loss and inconvenience to the community would be enormous. I feel that for this reason it will not be desirable to exceed very much in size stations of from 100,000 to 150,000 kw. Concerning present and future developments, I think some of the problems are by way of solving themselves. For instance, we know quite well that some of the London districts have found it to be commercially sound to link up their mains, and as time goes on many others will adopt the same course. In recent years also there has been a marked increase in the number of authorized undertakings who have purchased a bulk supply instead of constructing a generating station or carrying out extensions. The standardization of prices is also a most important problem

\* Journal I.E.E., vol. 44, p. 100, 1910.

which requires tackling by undertakings when established in areas such as Manchester. A great bar to extensions, in my opinion, is that would-be consumers do not understand why one town charges on one basis and at one price, and another town charges at a different price and on a different basis. It is impossible for us all to adopt the same average rate of charges, but I suggest that the charges can be based on a similar form so that they may be better understood by consumers. A further point is that I would deprecate any extension of some of the freak charges. No doubt they have been useful in certain localities, but I do not believe that on the whole they are good for the supply business. What with rateable values, maximum demands, telephone systems, standing and running charges, etc., people are simply befogged, and when they do not understand what it all means they are not likely to take a supply. One further observation I should like to make, namely, before the supply of electricity can be developed to the utmost it is necessary for the profession as a whole to agree as to the line which should be taken. We have seen, in the case of the London Power Supply Bills, what a "split in the camp" there is among those who occupy high positions. It is absolutely essential that we should compose our differences and present a united front as an Institution before we can accomplish anything in the nature of the formation of a Board of Control or even Joint Local Boards. One important matter which has to be decided in this country is that mentioned by Mr. Highfield in connection with the tenure of Orders. I am absolutely convinced that the granting of an Order to a Joint Board or anybody else should be in perpetuity. If we have only a limited tenure it is only common sense that we must charge much higher prices than we should do if we had perpetual powers, as we are placed in an uncertain position concerning what may happen at the end of the term.

Mr. C. C. ATCHISON : The main point in my opinion is that of the grouping and linking up of stations. There are certain areas where a linking up, such as Mr. Robertson recommends, would be suitable, and in general I agree with him that we cannot reasonably expect to link up all the undertakings throughout the country. I agree with the suggestion that there should be a Central Electricity Board in London, but its functions should be mainly in the direction of finance and general guidance. I do not think it should have very strong powers with regard to the local Boards ; let those deal with their own areas which they understand, and let London look after financial matters and the general guidance of undertakings so that there may be some standardization of systems throughout the whole country. At the present time, systems are very varied, and it would be difficult to link up the stations in certain areas owing to the difference of frequencies, etc., but under one Central Board there would be greater possibilities of standardization. These differences would be modified as the demands grew, until they could be practically eliminated. It has also been suggested that the Central Board should have the control of distribution and prices. That I cannot agree with. It is for the local Boards to deal with such matters as distribution and prices in their local areas. The fact of a number of local authorities being in close touch with one another and relying on interchange of supplies would naturally result in a tendency to uniformity of system of

supply, but I think it is almost impossible, even within the smaller Board's area, to fix standard prices. Conditions might prevail in the different districts which would not allow that to be done, and if we were to try to force standard prices it could only refer to a basis price and we should have to raise them in one district and lower them in another, or make arrangements for some interchange financially in order to meet the losses of one area out of the profits of others. With regard to the question of adjusting the supplies taken from the different stations, seeing that we are able to deal with an interchange of traffic over railways by means of a railway clearing house, I think it is a straightforward and simple matter to deal with supplies from one station to another. An Electric Supply Clearing House would be easy to work. Mr. Robertson mentioned oil fuel as compared with coal. If we could rely on satisfactory deliveries of oil it would be very convenient fuel to handle. The difficulties of handling coal, not only at the sidings but in some cases from them to the power station, would almost disappear, and we should have oil tanks emptied at a convenient goods yard into one end of a pipe line which would convey it to where it was to be consumed. This would save all the conveying and elevating plant necessary for coal, and the ash handling and disposal of ashes would disappear. The point to consider is, however, that we have coal of our own, whereas we should have to buy the oil from other people. If we have a supply of a commodity useful to us in our own country, let us use it and rely upon ourselves instead of going outside our country to buy from countries who may not always be friendly to us, and sea-borne supplies which might fail us in times of need. The question of erecting super-stations was touched upon by Mr. Watson ; in my opinion that is a matter which will practically adjust itself. When we start linking up, if we can get rid of coal freights by having stations at points where we are able to get reasonable supplies, the question of the cost of carting or the transmission of the coal will practically solve the question as to what size the stations should be in those areas ; and further large power stations in the neighbourhood of collieries would not necessarily mean cheap coal. In my opinion a number of fairly large stations properly interconnected would be a better and sounder arrangement than a few stations of large capacity individually. With regard to municipal profits and contributions in aid of the rates, I personally think that the ratepayers are thoroughly entitled to a reasonable return from their trading undertakings, but my feeling is certainly that those undertakings should not be "milked" in the way they have been in the past. There are many towns where the income from the trading departments is looked forward to in order to meet the liabilities in other directions, but I do not think that is treating such departments fairly, and neither is it just for the ratepayers who do not support the undertaking to reap the profits earned from those who do, nor does it give the undertaking an opportunity of extending and increasing the sale of the commodity for the supply of which they exist. The custom obtaining in Manchester of allowing a contribution of 1 per cent to the rates is a fair one, and I wish a number of other local authorities would deal with their electricity supply undertakings in a similar manner. The friction which, it is said, might exist between undertakings in connection with the linking up of systems, does not in

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my opinion arise from the engineers but is purely a question of the local councils. There is no doubt, with things developing as they are doing, we shall find it to be essential sooner or later that a large number of undertakings in certain areas should be linked up, and some of us, at any rate the engineers, are quite willing to consider such a scheme, with an interchange of supplies regulated, in the manner I have suggested, by means of a clearing house. When this arrangement of linking up comes to be adopted, I only hope it will be dealt with in a sound and uniform manner, certain standards being decided upon and adhered to, and that it will not be a repetition of the absolute muddle of our present systems of supply in local areas.

Mr.  
Wilkinson.

Mr. H. T. WILKINSON: It seems to me that after 14 years the dreams of the pioneers of the power companies are going to be realized. Considering the great difficulties they have had to face, the power companies have done exceedingly well, and seeing that there is a power company in each of the districts Mr. Robertson referred to I think they ought at least to have been mentioned by him. The companies are now linking up their networks with those of numerous other supply authorities, but not to the extent they might have done if their aims had been realized. If the spirit pervading this meeting had prevailed 12 or 14 years ago in Lancashire we might have had from three to six stations instead of 15. Much has been said about Parliament and Parliamentary committees. My view is that if we want to get on we must leave Parliament severely alone. There is no reason why the representatives of supply undertakings in Lancashire should not meet together and see what can be done. I would suggest, however, that they should have a strong independent chairman.

Mr. Wood.

Mr. W. J. H. WOOD: Mr. Williams' paper has given central station engineers food for thought, but Mr. Robertson has given us a practical solution of the difficulty and a workable basis for an Electricity Board. I certainly think the time is ripe for something to be done. With regard to linking up, all the linking up that is necessary can be done without a Board. If the authorities meet together they can make whatever arrangements they desire, and I am sure it would pay neighbouring public bodies to have their undertakings linked up. Many of the advantages of linking up have been clearly put forward, but one which has not been mentioned is in connection with extensions. Many of the smaller undertakings have to limit their extensions because they cannot enter upon any capital expenditure until they see some revenue on their capital, and many a good consumer is lost through the undertaking not being ready or able to offer the supply of power required. A certain amount of plant has to be kept as a stand-by, but, if undertakings were linked up, arrangements could be made with a neighbouring authority to allow a particular station which, in the near future, would have to be extended, to be loaded to its full capacity, its neighbour acting as stand-by and taking the overload. On the question of coal supplies I think a local Board such as Mr. Robertson recommended could control the prices, as well as the quality, and in that way many of the smaller undertakings would benefit. The big undertakings, owing to their large orders for coal, possibly get better prices than the smaller ones, but if they were to join together and be represented on one Board they would

be in a position to control prices to some extent. Another question which the Board might control and which has not been touched upon, is that of labour and the qualifications of central station engineers. There has been a great deal of trouble owing to men going from the smaller stations to larger ones because they get better wages, but if there were a Board which would regulate the rate of pay of labour—I do not mean that the smaller undertakings should pay less for labour; some ought to pay a great deal more than they do—it would reduce the difficulties occasioned by men leaving the smaller stations. I do not think, however, that it is possible for any Board to control the prices charged for electrical energy, which depend upon the circumstances and conditions prevailing in the district. Every undertaking should regulate its own prices, though for similar loads they might establish some standard basis of charging.

Mr. R. BLACKMORE: So far I have heard no serious reason given why the suggested Board should be formed. It would be unworkable so far as the prices charged to consumers are concerned. It has not yet been demonstrated that super-stations with coal-fired boilers can generate electrical energy more cheaply than an existing station having an output of from 20 to 50 million units per annum. In fact, at present the medium-sized stations are generating and selling energy at a lower figure than the larger stations. The selling price in various districts varies so much that the scheme would be unworkable. An electric power-supply scheme can only justify its existence if it can compete with the existing power plants which it hopes to supersede, and as the price of fuel varies to such a large extent in different districts, the price charged for electrical energy must vary accordingly and no standard price over a large area is possible. The suggestion of linking up the existing stations is a good one, but it is not necessary to seek the assistance of Parliament to link up our supplies. The linking up of tramways has already been a success. We have running powers between town and town, and interchange of traffic under such conditions that the number of car-miles run by each authority is practically the same at the end of the year. In the same way there is no reason why the various electricity undertakings should not have an interchange of supply which would no doubt be both economical and convenient. If by-product plant be available for steam-raising purposes in large quantities, the proper method of dealing with such supply would be by power companies financed by private enterprise, who would sell in bulk to the existing electricity supply undertakings.

Mr. E. K. SCOTT: I should like to know if the members of the proposed Board are going to be paid, because I do not believe in engineering work being done for nothing. I should prefer to see electricity supply controlled by a few paid expert commissioners, as is done abroad, e.g. in Australia and the United States. The railways and tramways of New South Wales are controlled by three commissioners who are experts and have very wide powers. Why cannot electricity supply in this part of Lancashire be controlled by three paid experts, each receiving a salary of, say, £2,000 a year? Give them powers to decide on matters of policy for the whole area, and to see that others carry out their recommendations. Government by committees is out of date. In the United States

Mr.  
Blackmore.

the public utilities such as electricity supply and transport are controlled by experts who are elected at intervals. These experts control both municipal undertakings and power companies, and they see that each undertaking receives fair treatment and that the public is properly served, whilst at the same time the capital invested receives a fair return. For some years I have observed this method of working by expert commissioners, and have come to the conclusion that it is infinitely preferable to the control by committees of amateurs. It is time our profession insisted that engineering matters should be controlled by engineers. Cheap electricity supply is a very vital necessity for this country, and it cannot be properly fostered and managed whilst it is largely in the hands of men whose horizon is that of the parish pump. Why should not power companies have the right to bring their mains into the cities and compete with the municipal plants? Competition by railways is beneficial to those towns and cities which are served by several lines. Then let us have competition in electricity supply. I want to see electricity sold at less than one-tenth of a penny per unit, and when the supply business is run on broad lines by experts, instead of on narrow lines by amateurs, I think such a price will be possible. Most of the little stations containing generators of a few hundred kilowatts capacity should be made into sub-stations. The size of a generating set for an up-to-date power-house is now at least 10,000 kw. Have not Messrs. Parsons built a 20,000-kw. set for a power-house in the United States? If 30,000-kw. sets are running in power-houses outside this country why should they not be installed here? They would be if electricity supply were taken out of the hands of people who have too narrow an outlook. If we are to compete in the world's markets in electrochemical and metallurgical products, electric power supply must be placed in the hands of the few who know and who, by training and tradition, can think and do things on a sufficiently large scale. The North-East coast is a district where electric power has been tackled in a bold way, and it is well known that supreme control is there exercised by two or three expert engineers. At Bitterfeld in Germany a power-house of 185,000 k.v.a. is being built for the special purpose of supplying electricity to two concerns for making nitrates from the air. That is the kind of thing we shall have to compete against in future. The manufacture of nitrates for fertilizers and explosive compounds is the biggest market that electricity has touched so far, and electrochemistry and metallurgy are likely to prove a more important load than traction, lighting, or power. If then we are to take our share in this new industrial development, we must be ready to generate electrical energy in power-houses on the scale of those in operation abroad, and at prices much lower than rule at present. This can be done by utilizing our coal supplies properly by recovering the by-products on a very large scale. If in Germany a 185,000-k.v.a. power-house can be built during war time to utilize a lignite coal deposit having only half the calorific value of our fuels, we ought to be able to do at least as well. These big developments will, however, never be carried out in this country whilst electricity supply remains largely in the control of committees of amateurs.

Mr. J. D. PATON: Previous speakers have referred to trouble with coal and colliery owners, but why do they

not make a movement to meet it? They may, if they Mr. Paton. like, form a nucleus of their present supply systems and centralize them in a balanced relation to the industrial areas, but they will have to take the main artery of any such system out to meet the mining interests, and place the heart of their nucleus in the mining fields. They must come out of their present field of purely technical electrical engineering and become mining engineers, in order to deal with the waste coals and the future supplies of coal for electrical power. Colliery interests will welcome the approaches of the Institution to solve the future problem of power production. Reference has also been made to the use of oil and the impossibility of its becoming an important factor in the future of electrical engineering; but the supply of oil for this country will not come from abroad. We have millions of tons of waste coal which yield 40 or 50 gallons of oil to the ton, but the coal owners cannot produce this material until a demand arises for it. Let electrical engineers place the vital centre of their power production in the middle of the fields controlled by these coal owners and use the gas, waste power, or coke which necessarily must be formed in the production of coal oil. If it be necessary to maintain existing power stations, supply this oil, or the residual coke, or preferably the gas from the processes, to them. This is the method I would suggest to electrical engineers. In one coal-field not far from where I am stationed there are 90 million tons of coal, the bed being about 5 ft. thick, which will show 40 to 60 gallons of crude oil per ton. Take the Wigan canal, from which we have been able to get 90 gallons per ton, and realize that at this moment it is worth in a crude form 5d. to 6d. per gallon. The coal which is now considered to be valuable will in the near future be relegated to a position of secondary importance. Coal fired only for its thermal value will become a thing of the past, and will take a secondary place to coal which will yield a high oil and by-product return. I suggest that the Institution should make a definite movement along this line and support those who are already working in this field. We should not only tackle coal, but also consider the national resources which we must use and the great advantages that will arise by adopting aluminium in the manufacture of electrical apparatus.

Mr. T. ROLES (*communicated*): I think Mr. Williams' Mr. Roles. scheme has much to recommend it, as it is based on the desired end being obtained largely by means of mutual co-operation between existing undertakings, rather than by the tackling of the problem on entirely new lines and the giving of the whole of the supply from large modern generating stations put down under such a new scheme. I am of the opinion that Mr. Williams' suggestions are such as would tend to a considerable extent to disarm opposition which has been experienced and may continue to be expected from existing electricity supply authorities and their engineers. A number of the proposals put forward by Mr. Williams are open to criticism, such as, for instance, the personnel of the proposed Electricity Board. It appears to me to be extremely doubtful whether any Government would consent to place such drastic powers in the hands of a Board in which Parliament had so little direct representation. I also think that in all probability opposition to such proposals would be forthcoming from the Home Office, the Board of Trade, and the Local

Mr. Roberts. Government Board; at any rate, I consider it to be unlikely that the permanent officials of these great departments would willingly consent to all questions and issues involved in the supply and application of electricity being taken out of their jurisdiction. Mr. Williams seems to have very carefully considered the whole question, and he has very rightly pointed out the advantages which would accrue through the fact that new stations could be laid out and built on a large scale at once. One of the greatest difficulties which have to be faced by engineers of electricity supply undertakings in connection with putting down a new station on modern lines, is that of immediately obtaining sufficient load to be economically dealt with by the new works and to provide revenue for the payment of the extra capital charges involved. If the new works can be started with an assured load, the existing works need only be relieved of just so much load as cannot be economically dealt with by the older plant. His point as to the desirability of regarding the giving of a supply in any part of the country not alone from the standpoint of whether it will pay to run the electric mains for the immediate demand, but also from the larger standpoint of whether giving such supply is for the good of the country as a whole, is also a good one.

Mr. J. A. ROBERTSON : I do not agree with Mr. Highfield that the railway systems of our country offer an example to be followed in centralizing electricity supply. We are, I think, far behind other countries in railway matters, although the railway companies have been free to develop their systems unhampered by restrictive legislation, while the wastage due to overlapping and the general inefficiency of operation provide very powerful arguments for the advocates of railway nationalization. I am not, like Mr. Highfield and Mr. McKenzie, consoled for the high price of fuel by the knowledge that gas departments and users of private plant are in a relatively worse position than central stations. Our object, I take it, is to supply power at the lowest possible price for manufacturing purposes, and particularly to re-establish our national industrial position after the war. To accomplish this we must have cheap fuel. The user of private plant is bound sooner or later to change over to electricity supply, and while high prices of fuel may accelerate the rate of change there is no reason why these prices should be artificially inflated to increase profits for colliery proprietors and middle-men. The principal criticism against my proposal to form Joint District Boards to control electricity supply is what Alderman Walker calls the "human element." Several speakers have emphasized the jealousy which exists between local authorities and also between central station engineers. Such feeling certainly does exist, but I think it has been very much exaggerated, and I am sure that if the engineers in a district will draw up and submit a workable scheme local authorities will gladly co-operate when the benefits of the scheme are realized. Mr. McKenzie fears that Manchester ratepayers would object to control by a Central Board because the electricity undertaking at present contributes £30,000 per annum towards the city rates. Mr. Atchison supports this objection and states that it is quite right and proper for the electricity undertaking to make such a contribution. I dissent entirely from the view that the ratepayers, of whom only a small number are electricity users, should receive a contribu-

tion of any kind from the trading departments. The primary object of municipally-owned electrical undertakings is to sell cheap electricity and not to make profits. At present the rates are often benefited at the expense of the reserve fund, while in some cases large contributions are annually made from undertakings which have no reserve fund at all. I hope that if joint control is adopted, this practice, which is unsound from every point of view, will be discontinued. Mr. Blackmore is strongly of opinion that Parliamentary assistance is not required, and that the Government is incapable of operating a business concern. It will be agreed, however, that some form of Parliamentary control is necessary for the operation of monopolies. It has been assumed that my proposal is to charge uniform prices in each district. I do not think I have made such a proposal. The Joint Board would be the authority to fix prices for each area or portion of an area, but it does not follow that the prices would be the same in each. Let me repeat that a linking-up scheme is not put forward as a permanent solution of the electricity supply problem. The high-tension mains would certainly form a part of any later scheme of bulk supply from large stations, and in the meantime the existing stations could be utilized very much more efficiently. It is probable that nationalization in some form will come later, but the problem is one to be dealt with immediately, and linking up will form a useful stepping stone to any national scheme of centralization. In referring to the nationalization of electricity supply one speaker quoted the Government mismanagement of the telephone system as an example. I think much of the criticism levelled against the Post Office Telephone Department is unfair and unjustified. The telephone system was taken over under circumstances of exceptional difficulty, and an immense amount of re-organization and new work had to be put in hand. On the other hand, advocates of nationalization can point to a Government department which has been created and organized within the last 12 months on a scale that would have been considered nothing less than a miracle before the War. It is true that this department has been organized chiefly by help from outside, but there is no reason why the same brains and the same public spirit which have assisted in building up the department of the Ministry of Munitions should not be at the service of the country to organize and develop the electricity supply business in times of peace.

(Communicated) As to whether Parliamentary powers would be necessary for the setting up of Joint Boards it would appear that under Section 8 of the Electric Lighting Act, 1909, the Board of Trade may issue a Provisional Order authorizing supply authorities to exercise jointly their powers under existing Acts or Orders. Several speakers in the discussion suggested that joint control is unnecessary and that supply authorities might voluntarily link up for mutual assistance. I am afraid this would only partly meet the end in view, and if joint control is not exercised, confusion and differences would inevitably arise. I quite agree with Mr. Watson that there is a distinct limit to the size of large generating stations, for reasons of safety and reliability, reasons which have not lost weight since aerial warfare has been introduced. As regards a cheap fuel supply, many of the medium-sized stations are ideally situated for a cheap supply of coal and could be extended

with a minimum of capital outlay. I entirely disagree with Mr. Highfield and Mr. Watson in suggesting that concessions to electric supply companies should be granted in perpetuity. The evils which undoubtedly existed in the early days through terminable concessions could be avoided as a result of experience, and in any case the dangers which would arise from the exercise of a monopoly granted in perpetuity are infinitely greater. I am much interested in Mr. Paton's remarks regarding the extraction of crude oil from waste coal. If the colliery owners are prepared to put down the necessary plant and the process can be worked at a reasonable cost, central station engineers will, I am sure, gladly welcome the opportunity of using oil fuel. Mr. Watson believes that some of the problems are solving themselves, and cites the London district which has already linked up. If progress is only made in the provinces at the same rate as in the London districts, it will take very many years to carry out any scheme for improving existing conditions. Organization amongst supply authorities is the keynote to future developments, and I am glad to see that so many engineers approve of the proposal for linking up power stations. I trust that some practical scheme for the industrial districts of Lancashire may be the outcome of this discussion.

Mr. E. T. WILLIAMS (*communicated*): I should like to correct a few wrong conclusions Mr. Robertson has drawn from the paper. He states that "the bulk-supply undertaking would be owned and operated by the State through a Central Board." In the summary of the paper, however, it is mentioned on page 586 that it should be clearly understood that my proposed scheme is not for the nationalization of our electricity supply, nor is it for the municipalization of that supply. Again, the paper does not suggest that the country is to be divided into six districts for supply purposes, but for the purposes of control under the Central Board, which is an entirely different matter. I cannot agree that "the stages to be passed" and "the difficulties to be overcome" have been overlooked in the paper. Such stages and difficulties have been most carefully considered and the proposals in the paper are the outcome, though the lengthy route by which the conclusions were reached has not been given. There is no suggestion in the paper to set aside the technical difficulties. The chief reason for the presence of six expert highly-paid electrical engineers on the Central Board is to assist in solving those difficulties. It is certainly not proposed in the paper to place the control of any one of the six districts in the hands of one engineer manager. The control of the electricity supply of any district would come under the Board as a whole. The true functions of each engineer manager would be (1) to be a technical member of the Central Board; (2) to represent the Central Board in one district; (3) to represent the electrical interests of that district on the Board; (4) to manage in his district such parts of the electricity supply as are the property of the Board. Thus, as an individual, he would manage only Board property in that district and not the property of municipalities, companies, or subsidiary Boards. On the operative side he would be responsible to the Board for managing the Board's own property. On the control side he would be responsible for seeing that the Board's decisions were made effective

in his district, and conversely for representing to the Board for their consideration problems arising in his district. There would be nothing to prevent any person, company, or body in that district presenting its case direct to the Board if so desired. The electrical engineer manager could also act as an intermediary for any joint efforts in his district and as an independent co-ordinating centre for such efforts. Mr. Robertson states "the Central Board would have no powers to compel a local authority to shut down its generating station, or to fix the price which the existing authorities are to charge for current." This was purposely omitted. We do not wish to impose restrictions where they can be avoided. The Board can withhold its approval for extensions or the replacement of obsolete plant unless it is satisfied it is in the interests of that town or district that this shall be given. This surely will have all the necessary effect. The price of current within the limits laid down in any district is mainly a local question. The Board could bring pressure to bear on any undertaking that was unreasonably using its powers by either running stations which could be more economically replaced by a bulk supply, charging higher rates than necessary, or paying an undue percentage to the relief of the town rates. I consider such local Boards as those proposed by Mr. Robertson would be an outcome of the larger scheme, which would be an important factor in enabling the local Boards to be formed. The services of the electrical engineer managers in their different districts would be valuable in this respect.

I hope the paper does not convey the idea that I propose to disregard the past history of electricity supply, for I agree with Mr. Highfield that to do this would be a mistake. The intention was to call attention to the new needs of our country, and that because many engineers had publicly advocated certain lines of policy in the past the new conditions called us to consider the subject from present needs rather than for defending our past proposals. I think there would not be great difficulty in arranging for the control of any local Boards by the Central Board, and this gives an added value to the Central Board. The Central Board itself would be responsible to Parliament, as explained in my communicated reply to the discussion in London (page 595).

Alderman Walker considers the cost of a site for a power station to be quite immaterial. I venture to suggest that no item of cost is immaterial. Other things being equal, the cost of a site is important, not only because very large sites will be required for the high-power stations of the future, particularly if the recovery of the by-products of coal is part of their operations, but also because we hope that industries requiring enormous supplies of electrical energy will grow up around the power stations.

Mr. Scott asks if the members of the Central Board are to be paid, and strongly advocates professional as against amateur Boards. In opening the discussion in London I stated that the members of the Board should be in receipt of salaries of not less than £2,500 per annum. All the members of the Board with the exception of the President would be expected to devote the whole of their time to the work of the Board. The Vice-President of the Board would be one of the electrical engineer managers.

## THE TESTING OF UNDERGROUND CABLES WITH CONTINUOUS CURRENT.\*

By O. L. RECORD, Associate Member.

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## INTRODUCTION.

"At the outset of electric lighting, as soon as there was a question of placing cables underground and of testing them after laying, the methods of insulation testing used by telegraph engineers to ascertain whether the cables after laying would meet the conditions required were naturally adopted. So long as only low pressures were in question, the problem without being negligible did not offer any great difficulty. It was gradually seen, however, that the tests should be made at a pressure at least equal to the normal, and that the conditions of testing must have some relation to the normal conditions of working. In the case of low pressures and telegraphic work insulation-resistance measurements give useful indications as to the state of the circuit and show if any defects have been caused in laying. As, however, the thickness of the insulation is always liberally calculated in such cases, there is little fear of a sudden rise in pressure endangering the cable; and, moreover, it is easy to make the tests at a pressure as high as any rise of voltage which is likely to occur, thereby ensuring the maximum possible safety.

"In the case of high-tension cables the thickness of the insulation is far from increasing in the same proportion as the voltage, and the point is soon reached where there is serious danger that a voltage-rise may puncture the insulation. One naturally asks whether the measurement of the insulation resistance is sufficient indication of a sound condition of the cable. The answer is that there is no definite relation between the insulation resistance and the dielectric strength, *i.e.* the resistance to withstand puncture.

"The present state of knowledge regarding dielectrics does not permit us to say that there is no relation between the two phenomena—resistance and dielectric strength. On the other hand, however, we cannot say that any relation does exist; in fact, it is easy to find various important differences between the two. For instance, the insulation resistance varies considerably with the temperature, so that an alteration of only a few degrees in the temperature will double the insulation resistance; whereas, although it cannot be said that the dielectric strength is independent of temperature, it must be admitted that at all ordinary temperatures the voltage which will produce a breakdown does not vary very much.

"The relation between dielectric strength and temperature is not known, nor has it been proved that it is the same for different materials. Our ignorance on this

subject is easily explained. The determination of the dielectric strength of solid insulating materials is a proof of everything or nothing. The sample under test resists at a certain temperature a known voltage and breaks down at a value slightly increased; but then the material is destroyed and a test at another temperature necessitates a further sample. Under these conditions it is necessary to have a dielectric remarkably homogeneous in order to obtain results which will allow us to determine the law of variation, especially as the phenomenon does not vary considerably with the temperature. It is probable that the puncture of the insulation only takes place at weak spots, as soon as the breakdown pressure of these points is reached, the result being that the fault can have only a very short length in the cable under examination; and, in consequence, as this weak spot would probably have a fairly high insulation resistance, its presence would not appreciably modify the mean insulation of the whole cable, especially when it is remembered that a rather large margin has to be allowed for inaccuracies in the measurements.

"Another feature seems to indicate that there is no direct relation between the mean insulation of the cable and the dielectric strength. In experiments with paper-insulated cables E. Höchstädter has studied the loss in a dielectric submitted to a high pressure at varying frequencies, and has compared the loss thus measured with the  $I^2R$  loss in the dielectric itself. Under the most favourable conditions (*i.e.* at a high temperature in which the insulation resistance is very low) the  $I^2R$  loss in the insulation only represents a very small fraction of the total loss.

"Since the measurement of the insulation resistance gives no indication of the dielectric strength of the cable, it is necessary to measure the latter directly, allowing a coefficient of safety sufficient to ensure that the voltage will never rise beyond that used for the test. This has already been done for some time, and tests on cables in the course of manufacture are always made to at least twice the pressure for which the cables are intended. The Engineering Standards Committee's specification actually prescribes a test at the factory and another test after laying to ensure that this operation has not caused any injury likely to produce breakdown of the insulation in the course of use. The test, after laying, is to be made at a pressure equal to approximately twice the normal, and is to last for 30 minutes."

"With medium-pressure and high-pressure cables there is little or no difficulty in making the verification after laying,

\* The portions of the paper which are between quotation marks have been translated from a paper by M. Armagnat, entitled: "Essais des Câblages Souterrains après Pose," read before the Société Internationale des Électriciens (*Bulletin de la Société Internationale des Électriciens*, Series 2, vol. 10, p. 613, 1910).

\* For the actual figures see the E.S.C. Report No. 7, pp. 12 and 13.

and it is usually sufficient to take a small transformer to any desired position for conveniently testing the cable; but as soon as it is a question of extra-high-tension cables, and of cables of great length, the problem becomes complicated. The apparent power, and in consequence the dimensions of the transformer necessary, increase as the square of the test pressure and directly as the total capacity of the cable. It is easily seen, therefore, that one very soon arrives at a transformer of such dimensions as to render transport very difficult.\* In practice, this difficulty in a number of cases has resulted in the tests after laying not being made at all, and in the engineer being content with measuring the insulation resistance; the latter gives an indication of certain defects, but takes no account of cracks or other defects produced during laying. This absence of verification naturally causes considerable uneasiness, and has already provoked a great deal of discussion. To remedy the situation it was proposed some time ago to make a test with continuous current at a pressure equal to the maximum reached in the case of alternating current, and various types of apparatus have been proposed for the purpose."

#### OBJECT OF TESTING CABLES AFTER LAYING.

Whilst an insulated cable for an underground network is being laid it is often subjected to strains or receives blows which crush or tear the insulating material or even pierce the lead. If there results a direct contact between one of the conductors and the lead, or if water enters the insulating material, in order to detect the fault it will suffice to carry out a low-tension insulation test with a magneto or a battery of dry cells. But if the insulation, crushed or twisted as it may be, still holds up, or if the water has not reached the conductor, the cable may be able to stand a pressure of several thousand volts without breaking down, and the test carried out at the few hundred volts given by the magneto or dry cells will indicate nothing.

The cable is then put into service. When the normal working voltage is reached, the weakened insulation will give way and a fresh fault will quickly show itself, with consequences sometimes disastrous, and always injurious, to the network and the machines. In order to avoid setbacks of this kind, it is thus necessary to submit the cables to a high-tension test before putting them into use.

After what has been said it will be seen that this test should have for its object, not to verify the dielectric qualities of the insulation, such qualities having been amply proved by the test at the factory during manufacture, but to ensure that the cable and the boxes, when laid, are in good condition.

This high-tension test becomes of so much the more, and a low-tension test of so much the less, value, as the working voltage at which the cable will operate is raised. As a rule, after having been laid the cable is tested at double the working voltage. Up to the present, for the want of static apparatus of sufficient power for this test, transformers have been used, or occasionally alternators connected direct to the cable. This is easy when it is merely

a question of testing a short network having a length of 1 to 2 miles, for example, to work at a pressure of, say, 5,000 volts or less, when the corresponding test pressure will not exceed 10,000 volts. The charging current at a frequency of 50 only reaches 2 or 3 amperes, and a transformer rated at about 20 kilowatts will be sufficient.

#### DIFFICULTIES IN TESTING WITH ALTERNATING CURRENT AFTER LAYING.

The question becomes complicated when it is a matter of testing, for example, at 40,000 volts, a network extending to something like 12 miles. The charging current might then reach as much as 27 amperes, corresponding to a power of 1,000 kilovolt-amperes. The dimensions of such a transformer can be imagined.

If a test is to be made, not in the factory but on site, the transport and drying-out of the apparatus involve practical impossibilities. Even if the transformer could be installed in the factory it would be extremely costly; and the fact that it could only be used once would often prevent its adoption on account of the expense involved, since this test should not be repeated—and in this lies one of the chief drawbacks to testing with alternating current.

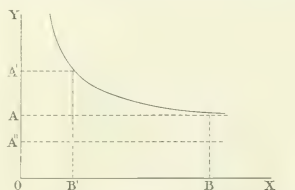


FIG. 1.—Relation between breakdown voltage (A.C.) and duration of test.

M. Laporte of the Laboratoire Central d'Électricité de Paris has found that the breakdown voltage for a dielectric under alternating pressure is a function of the time, as is shown in Fig. 1, distances along the axis OY representing voltage and those along OX the duration of the test.\* The ordinate OA is characterized by the fact that all pressures OA' higher than OA will cause a breakdown in a time OB' more or less short, and that all pressures OA'', appreciably lower than OA can be applied indefinitely without causing a breakdown. The breakdown-voltage limit OA causes a breakdown after about 15 minutes. M. Laporte has also found, at least in the case of solid and plastic insulating materials such as impregnated cellulose or 'india-rubber' used in the manufacture of cables, that the breakdown voltage decreases as the frequency increases. On changing from a frequency of 50 to 100 the curve of breakdown voltage is displaced in the direction of reduced ordinates. These facts, in conjunction with the well-known fact of the heating of dielectrics under alternating voltage, establish without doubt that alternating

\* If the figures given in Table E of Mr. E. H. Rayner's paper, "High-Voltage Tests and Energy Losses in Insulating Materials" (*Journal I.E.E.*, vol. 49, p. 10, 1912), are plotted, a curve of this kind is obtained.

In a paper read before the Elektrotechnische Verein and published in the *Elektrotechnische Zeitschrift*, vol. 25, pp. 2608 and 1921, 1914, Dr. L. Lichtenstein points out that the apparatus required for testing at 60,000 volts (alternating, 15 km.-on Swiss cable after laying might weigh as much as 25 tons, whilst the Delon apparatus capable of testing much greater lengths would only weigh 8 tons (see Appendix).

pressure causes fatigue of insulating materials; that is to say, their dielectric rigidity is not after a certain period of application of the pressure the same as at the beginning.\*

Moreover, it appears, and is well recognized not only by cable manufacturers but also by the majority of supply authorities, that this fatigue of insulating materials is permanent.†

The author would enlarge on this by pointing out that, from the general opinion of manufacturers, if one charges a cable to a voltage  $OA'$  in, say, 10 minutes, then removes the part where the fault is produced, and submits the rest to the same pressure  $OA'$ , the rupture will occur at the end of a very much shorter time, 5 minutes for example, and perhaps even instantaneously for a value  $OA''$  less than  $OA'$  or less even than  $OA$ .

A first breakdown, even if precautions have been taken to suppress pressure-rises of an oscillatory origin, produces the same effect as an increase of frequency; it lowers the breakdown curve. The application of a voltage in the neighbourhood of the breakdown value lowers the curve in a similar manner. The author cannot cite official experience to establish this fact, but he believes that the greater number of manufacturers have been convinced on this matter by their personal experiences.‡

It results from this, and it is at once very important and very unfortunate from the point of view of supply authorities, that manufacturers energetically oppose an alternating-pressure test higher than the working pressure being repeated on cables for which they have undertaken the guarantee. I say that this is unfortunate from the point of view of supply authorities, for the engineers responsible for these undertakings naturally wish to be able in some way to ascertain the condition of their networks by pressure tests performed either at periodic intervals or whenever an accident occurs which may have caused surges and submitted the insulating material of the cable to a dangerous strain. For all these reasons there is a call for another method of testing.

#### ADVANTAGES OF TESTING WITH CONTINUOUS CURRENT AFTER LAYING.

The continuous-current test, whilst it requires a certain amount of current to charge up the cable, absorbs no more after this charge is complete whatever the capacity of the cable, provided the insulation be sufficient. As can at once be seen, it therefore allows tests to be carried out with apparatus of small power after laying. Moreover, it does not fatigue the dielectric; at least, observations made in the case of continuous current have not shown any of the phenomena of fatigue observed with alternating current.

There is no heat produced in the course of the test; the breakdown voltage has a fixed value which does not decrease when the period of application is prolonged, and the curve of breakdown pressure becomes a straight line  $AR$  parallel to the axis of time (Fig. 2).

By employing continuous current, supply authorities can therefore as often as desired repeat their tests without raising the opposition of the cable manufacturers, and they can test at one and the same time, if not their whole

\* This point is clearly brought out in Tables L and M (page 14) of Mr. E. H. Raven's paper.

† The experiments described on pp. 13 and 14 of Mr. Raven's paper appear to confirm this, provided that the pressure is applied for a sufficiently long period.

‡ See note above.

network, the total insulation of which might be too low, at least all the feeders.

In virtue of the maxim, the truth of which has often been confirmed, that "Necessity is the mother of invention," there have been produced in the course of the last

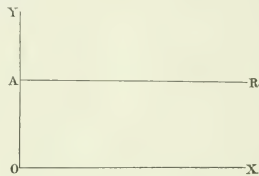


FIG. 2.—Relation between breakdown voltage (c.c.) and duration of test.

few years various types of apparatus of a practical nature for carrying out such continuous-current tests.\*

The author proposes to describe only one type of apparatus, viz. the "Delon" revolving contact-maker.

#### THE DELON APPARATUS.

This apparatus works on the following principle:—

"The essence of the apparatus is a high-tension contact-maker which charges condensers by making at each half period a connection through a short spark between the

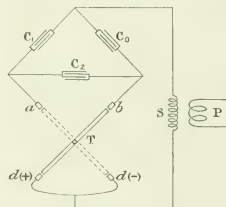


FIG. 3.—Principle of the Delon apparatus.

transformer and condenser to be charged. By means of a suitable arrangement the contact is made at the moment when the electromotive force is at its maximum value, and, by means of auxiliary condensers, the voltage of one half period is added to that of the other, with the result that finally the principal condenser is charged to a pressure double the maximum of the alternating current employed.

"Diagrammatically, the apparatus is reduced to that represented in Fig. 3.

"The contact-maker formed by a conductor,  $T$ , embedded in an ebonite disc revolves round a spindle perpendicular to the plane of the disc. Four fixed brushes are placed a very short distance from the disc in such a manner as almost to make contact with the conductor when the latter passes between them. These four brushes are placed at the extremities of two diameters which are perpendicular

\* For example, Mr. Watson's influence machine referred to by Mr. Highfield in his paper "The Transmission of Electrical Energy by Direct Current on the Series System," *Journal I.E.E.*, vol. 49, p. 852, 1912.

to the axis of the disc. Two of the adjacent brushes are joined together and connected to one of the secondary terminals of the transformer. The other two brushes are connected each to an apex of the triangular group of condensers to be charged, the other apex being joined to the second terminal of the transformer.

"The disc is driven by means of a synchronous motor fed from the alternating-current circuit which furnishes the high-tension current by means of the transformer. The group of fixed brushes can be placed at a convenient angle to allow of their coming opposite the moving conductor at the moment of maximum voltage; the condenser  $C_2$  to be charged, and the two auxiliaries  $C_3$  and  $C_4$  form a triangle of which the apexes are connected to the brushes  $a$  and  $b$  and to the transformer.

"At the outset, the synchronous motor being started, if the primary circuit of the transformer is closed the moving conductor  $T$  passes, say, first of all between the pair of fixed brushes  $b$  and  $d$  (+). The condenser  $C_2$  takes a charge which depends on the self-induction of the transformer and the maximum voltage of the secondary current. The other two capacities  $C_3$  and  $C_4$  take a charge such that the sum of their potentials  $U_3$  and  $U_4$  is equal to the potential,  $U_2$ , of the condenser  $C_2$ .

"At the following half period it is the condenser  $C_3$  which is directly connected to the secondary, and as the direction of the current is changed this condenser is charged in the same direction as in the previous case. The capacity  $C_4$ , on the contrary, receives a charge in the opposite direction to the first. As a result the capacity  $C_2$ , which is the one that it is desired to charge up to a high potential, receives charges which are always in the same direction, whatever the position of the moving conductor. The quantity of electricity supplied at each contact will then charge simultaneously one of the two auxiliary condensers in parallel with the group formed by the secondary auxiliary condenser and the capacity  $C_4$ . As the time during which contact is established between the transformer and the capacities is very short, and as, moreover, the self-induction of the secondary of the transformer is considerable, the quantity of electricity that can be introduced into the system at each half period is limited, but the repetition of the phenomenon is so rapid that at the end of a relatively short time the capacity  $C_2$  reaches a potential equal to twice the maximum pressure of the alternating current. In practice the charging-up is effected in less than a minute at a frequency of 50, that is, in less than 6,000 contacts.

"It must be clearly understood here that the word 'contact' signifies the passage of the conductor past the fixed brushes and not actual contact, the closing of the circuit being always produced by means of a spark, very short and of low resistance. One can easily conceive that with such a system it is possible to reach continuous charges as high as desired by using transformers of only comparatively small power.

"The interest of the problem that arose was to ascertain to what dimensions the employment of the apparatus described would lead, and whether it was possible to realize an arrangement which was practical, easy to handle, and convenient to use.

"The apparatus about to be described meets these conditions in a very practical manner. The whole of the apparatus is contained in a handcart, the total weight of

which is just over half a ton, so that it is quite easy for two men to wheel it. The cart contains in the back portion a small switchboard fitted with switches and regulators for controlling the synchronous motor and the primary circuit of the transformer. The synchronous motor is mounted directly on the shaft of the contact-maker; there is provided on the same shaft an asynchronous motor for starting purposes. The conductor which connects together the contacts is completely insulated in an ebonite disc, only the ends projecting. Four fixed brushes are mounted on an ebonite carrier which can revolve round the axis of the disc in order to give the brushes the correct position.

"All the apparatus that it is necessary to handle is placed in the upper part of the cart and is easily accessible when the side and back panels are lowered. The transformer is lodged in the lower part, below the contact-maker, and is very carefully insulated in order to prevent possible sparking between the terminals and the metal-work of the cart.

"The transformer is furnished with two primary windings which can be placed in parallel or series, allowing a voltage of 15,000 or 30,000 to be obtained on the secondary with a pressure of 110 volts on the primary side. With this appa-

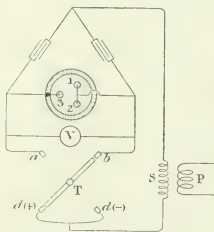


FIG. 4.—Diagram of connections for a 3-core cable (with auxiliary condensers).

ratus it is therefore possible to test cables up to approximately  $2 \times 30,000 \times 1.4$ , i.e. 84,000 volts; and by increasing the primary voltage it is possible to test up to 100,000 volts."

If necessary it is quite easy to produce and mount in a similar cart such an apparatus for 150,000 volts. For higher voltages, however, it is necessary to have recourse to a fixed installation, as the sparking distances which have to be considered become so great that a cart is out of the question. With a stationary apparatus constructed on the same principles and installed in the laboratory of the Société Française des Câbles Electriques, it is possible to get a pressure of 350,000 volts. A transformer of 3-kw. capacity has been found satisfactory for testing any network occurring in practice.

"The two auxiliary condensers can also be lodged in the upper part of the cart. An electrostatic voltmeter is provided in a special case, but it should be carried separately, as the jolting of the cart would be likely to damage it.

"With regard to the method of testing, either the two auxiliary condensers can be used, or in the case of multi-core cable they can be dispensed with, one or two of the

conductors and the lead taking their place. Fig. 4 shows the connections with the condensers. One of the conductors is connected to the lead and then to one of the fixed brushes, and the other two conductors are joined together and connected to the second brush. The two condensers are joined together and their common point is connected to one of the secondary terminals of the transformer. As will be seen, therefore, the test is made between conductors 1 and 2, and conductor 3 and the lead. In order to complete the test it is therefore necessary to make a second test, joining conductors 1 or 2 to the lead and the other two conductors to the fixed brush *b*. In actual practice the auxiliary condensers are usually dispensed with, the cable itself providing the capacity."

Fig. 5 shows the connections for a 2-core cable. In this case one of the conductors of the cable is subjected to a pressure always of the same sign and equal to the maximum positive value of the alternating electromotive force, viz.  $+E/\sqrt{2}$ , and the other to a pressure equal to the maximum negative value, viz.  $-E/\sqrt{2}$ , so that there is at any instant between the two conductors under test a difference of potential equal to double the maximum voltage, viz.  $2E/\sqrt{2}$ .

This result is obtained as follows:—

The transformer, constructed for a ratio of 110 (or 220) to 30,000, is supplied with alternating current which drives at half the speed of synchronism the synchronous

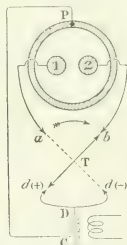


FIG. 5.—Diagram of connections for a 2-core cable.

motor connected across the transformer. This motor has keyed on to its shaft the metallic conductor, the ends of which, when revolving, pass very near to the four small metal brushes *a*, *b*, *d*, and *d* (-). The same letter is given to the last two brushes, which being joined together to the same high-tension terminal D of the transformer perform the same function. Suppose that a 2-core lead-covered cable has to be tested and that the capacity measured between the conductors and between the conductors and the lead is so small that the charge it takes is not sufficient to react upon the pressure at the high-voltage terminals of the transformer, the brush *a* would be connected to one of the conductors which is designated by the number 1, and the brush *b* to the other conductor 2. The terminal C of the transformer opposed to D, after being connected to the lead P of the cable, is earthed; the potential of C is therefore fixed.

Let us consider what happens, commencing at the

moment when the conductor T revolving in the direction of the hands of a watch occupies the position *d*.

Suppose that it is arranged on its axis in such a way that at the instant it occupies this position *d* the potential at the terminal D has reached its positive maximum; the conductor 2 will then be charged to the potential  $+E/\sqrt{2}$ , *E* being the virtual electromotive force. The lead being at zero potential, the conductor 1 which is insulated will assume a potential intermediate between zero and  $+E/\sqrt{2}$ . The transformer has only to supply the small charge due to the pressure  $E/\sqrt{2}$  applied to the capacity of the conductor. After a half period of the alternating pressure, D will be at a negative potential  $-E/\sqrt{2}$ , and the shaft of the motor and the conductor *d* revolving at half synchronous speed will have made a quarter turn and *d* will be in the position *a*. The metallic conductor will establish connection between *d* and *a*, which will be raised to the potential D, since we have supposed it will take a charge too weak to react on the potential of D. There will be therefore at this moment a difference of potential  $2E/\sqrt{2}$  between the two conductors, and  $E/\sqrt{2}$  between each conductor and the lead. A quarter of a turn later the metallic conductor will have returned to the position *d* and will charge afresh conductor 2 to a potential  $+E/\sqrt{2}$ . If the insulation is sufficiently great (and one sees thus the importance of this condition) the loss across the dielectric during half a turn of the shaft will be negligible and the transformer will have no appreciable loss to make up.

The conductors, by the successive contacts with the two brushes, will keep their potentials at the values  $+E/\sqrt{2}$  and  $-E/\sqrt{2}$  respectively, and it is easy to verify this by inserting an electrostatic voltmeter between *a* and *b*.

Suppose now that the capacity of each of the two conductors is considerable. The transformer cannot supply during the first contact the charge corresponding to the product of the potential  $E/\sqrt{2}$  by the capacity. There will be a drop of potential and the value attained will be less than  $E/\sqrt{2}$ . It will only be after a certain number of passages of the conductor between the brushes that, the potential between *d* (+) and *b* and between *d* (-) and *a* respectively decreasing, the drop of potential in the transformer will be compensated and the potential of *b* will become exactly equal to that of *d* (+), and that of *a* to *d* (-). Conductor 2 will then be at a potential  $+E/\sqrt{2}$  and conductor 1 at a potential  $-E/\sqrt{2}$ , each of them being at a potential  $E/\sqrt{2}$  with respect to the lead.

This is clearly shown on the electrostatic voltmeter connected between *a* and *b*, the pointer of which only reaches gradually the point on the scale corresponding to  $2E/\sqrt{2}$ , the time required being longer the greater the capacity of the cable.

In practice the maximum pressure is always obtained within a few minutes on a well-insulated cable system.

If it is desired to test between each conductor and lead at the same pressure as between conductors, it is necessary to connect brush *a*, for example, to the lead, conductor 2 to the terminal of the transformer C, and brush *b* to conductor 1. After having thus made the test with the full potential between conductor 1 and the lead, reverse the connections to 1 and 2, and there is then the full potential between conductor 2 and the lead. At the end of these three tests the maximum potential will have

been applied successively between the two conductors and between each conductor and the lead.

#### METHODS OF TESTING CABLES HAVING VARIOUS NUMBERS OF CONDUCTORS.

"To test under the same conditions a cable with 3 or 4 conductors, in order to test all parts of the cable under the maximum pressure it is necessary to make the following connections—two groupings with each scheme, or four tests in all.

"In the scheme Fig. 6(A), conductor 3 forms the intermediate point and is connected directly to the secondary terminal of the transformer. The other two conductors

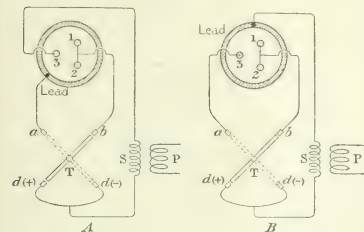


FIG. 6.—Methods of connecting up for 3-core cables.

joined together form one of the coatings of the condensers to be charged, the other coating being represented by the lead. In this case the maximum pressure is established between the conductors 1 and 2 and the lead. It is necessary to make a second grouping, taking as the intermediate point one of the conductors 1 or 2 in order to test between conductor 3 and the lead.



FIG. 7.—Method with single-conductor cables.

"In the second scheme Fig. 6(B), the lead is taken as the intermediate point and the maximum voltage is then between the conductors. It is therefore necessary to make two different groupings, viz. conductors 1 and 2 connected together against 3; conductors 1 and 3 against 2; or conductors 2 and 3 against 1."

A difficulty presents itself in the case of single-conductor

cables, since there are only two metallic portions, the lead and the conductor, whilst there are two terminals on the revolving contact-maker and one on the transformer.

In most cases single-conductor cables are constructed to transmit low-tension current. The Delon apparatus being ordinarily constructed for a pressure of 100,000 volts, one can easily obtain the necessary test potential by using, for example, only brush *a* and the terminal C of the transformer, which will give half the total potential developed by the revolving contact maker (Fig. 7). The brush *b* will not be used, no difficulty being caused thereby. It is therefore evident that in all practical cases the insulation of each of the conductors of a cable, whatever their number, can be submitted to the potential desired.

As to the merits of the two methods with or without auxiliary condensers, it is difficult to decide. By using condensers the tests on a 3-core cable can be reduced to two, but this necessitates the carrying of condensers. Circumstances would determine the choice of method.

#### MEASUREMENT OF THE POTENTIAL. THE ABRAHAM-VILLARD ELECTROSTATIC VOLTMETER.

The author now proposes to call attention to the apparatus which serves to measure directly the difference of potential. It is an electrostatic voltmeter designed by M. Villard, Member of the Institute of France, and M. Abraham, Maitre de Conférences à l'École Normale Supérieure, and constructed by the firm of Carpentier. It is based on the principle of the Kelvin electrostatic voltmeter, but the moving system and the pointer are enclosed in a metal case in the side of which moves a plunger that is protected by means of a large guard disc, the whole being connected to one of the high-tension terminals. A foot moving in a slide carries another disc which is connected to the other terminal. Between these two discs, and particularly between the surface of the plunger placed in the centre of the first disc and the second disc, a perfectly uniform field is established. The apparatus is graduated empirically and will operate at varying degrees of sensitivity according to the different positions occupied by the moving disc.

The instrument can measure up to 100,000 volts either continuous or alternating. It is quite handy, easy to set up, and not particularly cumbersome. After dismantling, it can be packed in a case, thus making of it a really practical piece of apparatus for tests on underground mains.

#### THE POTENTIAL TO ADOPT.

A difficult question now arises: we have seen that a continuous-current test does not fatigue the dielectric in the same way as an alternating-current test, the latter sometimes leading to a breakdown; but are the values on the one hand of the continuous potential, and on the other hand of the equally effective alternating potential, equivalent from the point of view of breakdown? If not, what value is it necessary to adopt in the case of a continuous-current test in order to ensure that all the defects which would have shown up in the case of an alternating test of double the working potential will show up under the continuous potential?

The experience of M. Laporte has shown that a continuous potential will only produce the same breakdown effect

as an alternating potential of one-third to one-fourth its value, whilst one would have expected only the ratio  $\sqrt{2}$  to 1. These are merely the results of laboratory tests, and the author fully recognizes that practical engineers will perhaps only accept them for what they are worth. They are, however, confirmed by other results obtained in practice.\*

In Paris there was a breakdown on one of the main feeders. The breakdown having subjected the system to so severe a strain that it was necessary to take care not to renew it, the cable, after repair, was tested with the Delon apparatus. It broke down afresh when the volt-meter indicated 18,000 volts (continuous), and again after being once more repaired. It was a cable of somewhat ancient manufacture not possessing a sufficient factor of safety. On pulling up the ends for 2 or 3 yards it was found that they flashed over on alternating current at 5,000 volts, and on continuous current between 15,000 and 20,000 volts, thus agreeing with the above ratio.

#### BURNING-OUT OF FAULTS.

Another objection has been raised. By the application of continuous current with such a small amount of power, is it possible to reduce sufficiently the resistance of a fault as to enable it to be easily located by the ordinary methods, viz. by a "loop" test or the "drop of potential" method?

"To prove that this was possible, special tests were made, an artificial fault being burned out completely under the following circumstances:—

"A piece of 3-core cable, 50-sq. mm. section, 20 yards long, designed for a working pressure of 10,000 volts, was connected to the testing apparatus, as shown in Fig. 6(A). In its normal condition this cable withstood a pressure of more than 80,000 volts, and to obtain a fault it was necessary to flatten it out with a hammer near one end. The cable thus injured withstood 74,000 volts; but on increasing the pressure to 80,000 volts the voltage suddenly dropped to 32,000 and remained at that figure some time. At this point the insulation resistance was too high to be measured with a galvanometer and battery; it was therefore impossible to localize the fault in the ordinary way. On forcing the transformer and increasing the total current, including that taken by the synchronous motor, to about 10 amperes at 110 volts, the pressure gradually decreased and fell to zero at the end of 8 to 9 minutes, the insulation resistance falling to zero at the same time and the galvanometer indicating a short-circuit. On opening up the cable it was evident that the puncture had occurred between the cores and that the subsequent charges had been sufficient to carbonize the insulation completely, thus rendering impossible the masking of the fault, which often takes place when a simple puncture is produced by a spark, the impregnating material flowing into the fault and hiding it."

Practical experience has also shown that the desired result can be obtained in less than a quarter of an hour. The resistance of the fault on the cable mentioned above was reduced in a few minutes to 14,000 ohms, and examples are sufficiently numerous for it to be said that the

\* Dr. Lichtenstein in the paper referred to above gives as the result of various tests a mean ratio of 2.6:1. For details of these tests see the Appendix.

apparatus, such as it is, meets all the conditions arising out of the tests of cable networks.

#### INDEFINITE REPETITION OF TESTS.

Finally, and this seems one of the greatest advantages of the system, continuous-current tests do not fatigue the dielectric, even if they are applied at frequent intervals, thus fulfilling the requirements of supply authorities as previously mentioned. Indeed some of the large electric supply undertakings on the Continent, among others the Compagnie du Gaz de Lyon, the Société Grenobleise de Force et Lumière, the Société Le Triphasé de Paris, the Compagnie du Gaz de Valenciennes, and the Société des Houillères de Huta Bankowa, Russia, have definitely adopted the system, and it renders them excellent service in testing their cable systems, which extend to a length of as much as 12½ miles.†

#### PRACTICAL TESTS.

"The apparatus shown has already been tested in practice, in particular in the case of some tests carried out as long ago as 1910. The apparatus in question was used in Lyons for testing a cable 2 km. long, laid for the Société Grenobleise. It was required to test a 3-core cable of 40-sq. mm. section, designed for a working pressure of 10,000 volts. This cable was to be tested at 30,000 volts, i.e. at approximately  $2\sqrt{2}$  times the normal working pressure. As the cable ran near a cable factory, the current was taken from this factory supply at 180 volts, and was reduced to 110 volts by means of a choking coil. The connections were as shown in Fig. 4, auxiliary condensers being used, each having a capacity of 0.015 mfd. The capacity of the cable was about 0.4 mfd. If it had been necessary to make the test with alternating current a transformer of 50-k.v.a. capacity would have been necessary. With continuous current, experience showed that a pressure of only 105 volts at the primary terminals and a current of 2.9 amperes, i.e. 305 volt-amperes, were necessary, whilst the potential reached was 31,000 volts.

"In the second case a test was made on a cable about 12 kilometres long of the same type as the preceding and of  $3 \times 25$ -sq. mm. section. This cable adjoined the works of the Compagnie des Omnibus et Tramways de Lyon, and the test was made in these works with the current taken from the mains. In this case the capacity of the cable itself was employed instead of auxiliary condensers in order to obtain values most comparable in the three branches of the circuit. The capacities were as follows:—

" 1.4 mfd. between two conductors and the third.	
2.44 " " " " " lead.	
1.54 " " " one conductor " lead.	

"The connections were as shown in Fig. 6."

It is interesting to note that for an alternating-current test on this length of cable a transformer of 300-k.v.a. capacity would have been necessary. The actual load taken from the mains never exceeded 3 amperes at 110 volts, or 330 volt-amperes.

\* There are now few cable systems of importance in France in which the Delon apparatus is not used.

## CONCLUSION.

"What is the nature of the charge given to the cable? Does it oscillate, or is it sufficiently constant to be considered as furnished from a source of continuous current?

"Tests with the oscillograph have shown that the quantity of electricity taken at each contact is less than 2·8 micro-coulombs, the maximum current being less than 7 milli-amperes and the duration of each charge less than 1/50 period. The corresponding pressure variation was less than 8 volts, which is perfectly negligible compared with the total pressure of 30,000 volts. One can even say that the pressure is infinitely more constant than that supplied by a dynamo.

"It is evident, therefore, that the apparatus shown allows of tests on underground cable systems being easily carried out with constant pressure.

"Various objections have, however, been raised to the method. For instance, some engineers think that the causes of puncture of cables are quite different with alternating current from what they are with continuous current; also that the test gives a false security and that in specifying a continuous-current test quite new conditions are imposed on the manufacturer, conditions which are quite useless from the point of view of the service for which the cables are required." It appears, however, quite a simple matter to establish the relation between the alternating and continuous pressures which will produce the same disruptive effect. As mentioned before, M. Laporte found a factor of 3 to 4, but investigation has shown that the ratio varies somewhat with the nature of the insulating material. If, however, the cable-makers and the supply authorities could agree as to the value of the test pressure which should be adopted for a particular insulating material, all objections would disappear, especially if it is borne in mind that the tests in question are only intended to show up faults which may have been produced in laying the cables, such as cracks in the insulation, entrance of moisture, etc., and not to verify the dielectric qualities of the insulation.

The author wishes to express his indebtedness to M. Armagnat, M. Delon, and to the Société Française des Câbles Électriques for information and drawings which they have very kindly placed at his disposal.

## APPENDIX.

In the paper read before the Elektrotechnische Verein and published in the *Elektrotechnische Zeitschrift* (vol. 35, pp. 1008 and 1021, 1914), referred to in the footnotes on pp. 609 and 614, Dr. Lichtenstein gives an account of some experiments carried out to determine the ratio of the continuous-current pressure given by the Delon apparatus to the alternating high-tension pressure. If the capacity of the cable was sufficiently great this ratio was found to vary between 2·35 and 2·45, and can therefore be regarded as practically constant. For very high pressures the ratio is slightly less. As a test, connection was made to 150 metres of highly insulated rubber cable, and it was found that a continuous-current pressure of 200,000 volts corresponded to an alternating pressure of 100,000 volts. For very

short cables the ratio is less, and it is then an advantage to insert considerable capacity in parallel with the cable.

The table below gives the ratio of the continuous to the alternating-current pressure if the tests are carried out in this way.

These values were obtained on a 3-km. length of 3-phase cable for 10,000 volts, each of the cores having a cross-section of 35 sq. mm. For low voltages the ratio of the continuous-current pressure to that of the alternating current is rather low, which is probably to be explained by losses at the spark contacts. The time taken to charge up the 3-km. length to a continuous-current pressure of 80,000 volts was only about 40 seconds.

Breakdown tests were carried out on 60 test-lengths of paper-insulated cable; half the tests were with continuous current, and the other half with alternating current. The mean value of the breakdown voltage with alternating current was found to be 16,550 volts, and with continuous current 44,150 volts. The ratio between these figures is 1 to 2·67. The variations of single readings from the mean did not exceed 7 or 8 per cent in the two cases. Other tests of a similar nature confirmed this ratio. All the

A.C. Pressure Kilovolts	C.C. Pressure Kilovolts	Ratio	A.C. Pressure Kilovolts	C.C. Pressure Kilovolts	Ratio
10·0	16·0	1·6	40	98·5	2·46
12·5	28·0	2·24	50	120·5	2·43
15·0	35·5	2·36	60	143·0	2·38
20·0	48·8	2·44	70	158·0	2·26
30·0	73·7	2·46	80	175·0	2·18

breakdown tests lasted about 2 minutes, and, for the reasons explained above, a length of 250 metres of a 3-phase 20,000-volt cable was connected in parallel with the test-piece. With rubber-insulated cables similar tests were carried out on a large number of samples each 120 cm. long. In these cases the tests were divided into three separate sets. The first showed a ratio of 1 to 2·8, the second set gave 1 to 2·45, and the third 1 to 2·5. These values are not very different from that obtained with paper-insulated cables. Tests were also carried out on a number of samples of cables for 700 volts, each sample being 2½ metres long. These gave a mean value of the ratio as 1 to 2·53.

Dr. Lichtenstein also describes a portable Delon apparatus in use by the Siemens Schuckert firm. The transformer is rated at 10 k.v.a. at 100,000 volts on the high-pressure side, with 500 volts on the low-pressure side at a frequency of 50. As a 500-volt 50-cycle supply might not always be available, a petrol engine running at 1,500 r.p.m. is used, coupled to a small alternator giving 9 kw. at 500 volts. The engine has a flywheel and governor, and thus runs fairly steadily. If the load is suddenly thrown off, the speed rises only 12 per cent. A very carefully arranged adjustment allows the voltage to be varied between 50

and 500. The whole of the apparatus is carried on a wagon as described in the paper, with the exception of the transformer, which is carried on a second wagon. The weight of the two wagons with their apparatus is about 8 tons, and the set is capable of testing as much as 50 km. of cable to 150,000 volts, while the weight of a corresponding alternating-current equipment for testing a length of only 15 km. would be about 25 tons. As Dr.

Lichtenstein points out, the advantage in weight is quite surprising; furthermore, a test which formerly took in many cases several weeks, owing to difficulties of transport and the time occupied in arranging the apparatus, can now be carried out in a few days. It is also possible to complete the testing of the cables before the central station is ready to supply power; and this is often an advantage of great value.

#### DISCUSSION BEFORE THE INSTITUTION, 10 FEBRUARY, 1916.

Mr.  
Wellbourn

Mr. B. WELBOURN: I should like for a moment to be allowed to depart from the strict order in which our meetings are conducted. I have heard within the last hour or two, with the greatest pleasure, that our President's eldest son, who is in the Royal Engineers and is an Associate Member of the Institution, has been awarded the Military Cross for valour in the field. The President's youngest son has also obtained the same decoration\* and has received promotion after 16 months of trench warfare. I think members will agree with me that the Sparks family is doing well, seeing that not only have two of them gained distinction, but Mr. Sparks' other son and his brother are also doing duty at the Front.

Turning now to the paper, I should like to enter a slight protest against its form. It is usual in presenting papers on any subject to pay some tribute to the work of others in the same field, and I could have wished that the author had given us first a general treatise on the different methods which have been proposed and actually used for the continuous-current testing of cables. In particular he might have referred to the excellent work which Mr. E. A. Watson has done and which was described before the Institution some years ago.† There is nothing new in the use of continuous current for testing cable networks. Fifteen years ago I was using continuous-current machines for testing the c.g. cable networks then so much in vogue, and the method was only given up for two reasons: first, because of the great increase in the number of alternating-current networks, and, secondly, because the 2,000-volt continuous-current motor-generators which were available were of such flimsy construction that they were always breaking down for mechanical reasons. With the great improvements which have taken place in continuous-current machines, particularly for traction work up to 5,000 volts per commutator, it is quite easy now, by putting two or four machines in series, to get up to 10,000 or 20,000 volts. This affords a subject for very much thought among cable engineers as to whether there might not be some reversion to continuous-current testing of alternating-current systems, say up to 10,000 volts, with the apparatus now available, seeing that Dr. Lichtenstein and M. Laporte have established some sort of relationship between continuous-current and alternating-current pressures. I think the author has not made it quite clear that one should differentiate between the tests which are carried out on cables. I think he will agree that where cables are to be used for alternating-current transmission, the tests on them at the makers' works should be

made with alternating current and not continuous current, because the cables must be tested for dielectric hysteresis. On the other hand, after the cables have been laid it seems to me that it is merely necessary, as the author says, to ascertain that the cables have not been mishandled and to test the joints. Sample joints can of course be tested at the works to satisfy oneself that the joint *per se* is satisfactory, but we do want some method which can be easily applied of testing the soundness of the installation when it is completed, and I think this is where continuous current may possibly find considerable application. I have recently had a case where a number of 9-mile lengths of 20,000-volt cable had to be tested at 40,000 volts and 25 cycles. That means the provision of transforming apparatus capable of giving an output of 1,290 k.v.a. and weighing upwards of 20 tons, which is a very serious proposition, not only from the point of view of first cost, but also of transport from one point to another. Then it is necessary to bear in mind the increase of transmission pressures. We now have 33,000-volt cables, and I think that 50,000-volt 3-core cables may be used in the near future in this country; in fact, they have already been proposed for one important scheme. It will be seen that to test a 50,000-volt cable in perhaps 20-mile or 30-mile lengths at 100,000 volts and a frequency of 50 is an impossible proposition, commercially, and therefore we must seriously consider the use of a continuous-current pressure. To my mind the main thing is to satisfy the users of the cables that the continuous-current test is a practicable proposition. As the author says, if we get a breakdown under continuous current with practically no power behind it, we merely puncture the insulation and we may or may not be able to burn the fault out. I have seen several miles of cable charged to a potential of 130,000 volts (continuous current) and then discharged at one end, the spark obtained being terrific. When the insulation is pierced in such a case, I believe that the stored energy would be discharged through the puncture, thereby providing the cleanest burn-out that could be desired. The advantages of the continuous-current test are considerable. We have a readier means of dealing with any moisture in the cable—the effect of alternating-current pressures is to disperse moisture, whereas with continuous current osmosis helps us and all the moisture is concentrated at one point, so that the period during which a breakdown may occur should be considerably shortened. A second advantage is that much greater lengths of cable can be tested at one time with commercial apparatus. Before committing oneself to continuous-current apparatus, however, one must be satisfied that the apparatus is satisfactory. I have had no

\* *Journal I.E.E.* vol. 53, p. 472, 1915.

† *Ibid.*, vol. 37, p. 295, 1900; vol. 43, p. 113, 1906; vol. 45, p. 5, 1910.

experience with the apparatus which the author describes, and I should like to ask one or two questions about it. First of all, the author remarks that the oscillograph tests show that the nature of the current is not oscillatory. Can he show us any of those records? Secondly, he refers to quantity tests deduced from oscillograph records, but he omits to mention the length of cable connected to the apparatus. Perhaps he will give us that information. The author makes one or two rather disparaging remarks about opposition from cable manufacturers, and I think he must have had in mind French manufacturers rather than British manufacturers in making that statement. Again, in connection with Fig. 1, I think he would perhaps have gained more sympathy from cable manufacturers if he had paid some tribute to the work on similar lines which has been done in England. Sir John Snell's book\* contains an exactly similar curve, which was prepared 10 years ago by my colleagues and myself in conjunction with Mr. Bernard Price from data obtained on the first 20,000-volt 3-core cables constructed in this country. I do not agree with the author's remark that this curve indicates dielectric fatigue. Our experience with this curve was that if we applied, say, 50,000 volts to a 20,000-volt cable we could, after a definite time, break down the cable; whereas if the pressure was removed just before breakdown and the cable allowed to cool, the same cycle could be gone through indefinitely, and one could predict within a quarter of an hour exactly when the failure would occur. I think, therefore, that as regards modern paper-insulated power cables the author's statements about dielectric fatigue do not hold good when tested at the usual frequencies at which power is supplied. In conclusion I should like to say that, instead of the author having to convert the cable makers, his campaign will have to be carried out among the cable users.†

MR. A. P. TROTTER: Before discussing the paper I should like to have re-read the scientific work of Mr. Evershed and Mr. Addenbrooke, and the practical papers by Mr. Beaver, Mr. Vernier, and others on this subject, which is related to dielectrics and the testing of them. I think we have not had for a long time a paper on cable testing which compares the Continental method of breakdown on flash test, and the time test, which has been more common in this country, and I do not consider this paper does so. For a long time it has been the custom to test for half an hour. In the old days that was quite easy. Then one began with double the working pressure. When, however, the extra-high-pressure cable was introduced, the rule was to test at double the voltage up to 10,000 volts, and at the working pressure plus 10,000 volts for anything higher than that, since in those days one could not find the apparatus to carry out the test in any other way. Half an hour was still the nominal time, but it introduced difficulties. The time question does, I think, want more consideration than it has yet received. Mr. Vernier gave some examples of the effect of time, and Mr. Evershed in his recent paper‡ gave a time curve similar to Fig. 1, pointing out the necessity for the careful interpretation of that time curve. If we find that we are well over the knee of the curve we have only to plot with

a different set of abscissae and we find that we are far from that point. One therefore cannot draw conclusions from the curve without knowing a good deal about the quantities involved. The actions which occur in a cable under electric stress have been the subject of a great deal of scientific work, and I believe that practical men are rather divided in the application of those scientific principles. The author says at the beginning of the paper that "there is no definite relation between the insulation resistance and the dielectric strength," but later he appears to assume there is some relation. The object of the test after laying is to discover any defects which may have been produced; but, as Mr. Welbourn has said, the most important point is to find out whether the joints have been properly made. One would like to hear from practical men to what extent a large length of cable can be cut up into convenient sections for testing. The networks of cables are extending every day. In the second column on page 609 the author considers it to be difficult to test 12 miles of cables at 40,000 volts—I assume that to mean a 30,000-volt cable tested at an additional 10,000 volts. If the cables can be treated in shorter sections, the difficulties would, of course, be largely decreased. The test could be made from various sub-stations and generating stations, and that is a question on which I should like to hear the opinions of practical users of cables. I had hoped that, with the scientific work of Mr. Addenbrooke and the test Mr. Rayner suggested some time ago, of superimposing a small testing continuous current upon the alternating current, and merely observing the fall of resistance, one might have predicted rather more quickly what was going to happen to a cable, and might thereby have shortened the period of testing. I think it is now open to doubt whether a test lasting half an hour is really wanted. In the old days cables did break down after 20 minutes' test, and I remember my predecessor, Major Cardew, telling me that the period of half an hour ought not to be diminished. The question now arises, however, whether under modern conditions of 3-core cables at extra high pressures the cable after being subjected to a very great pressure for 20 minutes is being injured, or at all events weakened temporarily by heating of the dielectric. On the other hand, to test with the working pressure plus 10,000 volts allows practically no margin of safety for ordinary surges that may arise every day.

MR. F. C. RAPHAEL: I am glad Mr. Trotter called attention to Mr. Evershed's paper, because I intended to do so, and also to the discussion on that paper. Reading that again, after a lapse of time, especially with the full report of the discussion in the *Journal*, permits one to gather a great deal about what really occurs in the dielectric of a cable. I think Mr. Welbourn is expressing only his personal view when he says that cable makers do not object at all to the user repeating the alternating-current breakdown test. There is a distinct objection to this, and quite rightly, because it involves possibilities of overdoing things, for instance setting up resonance effects from the test itself, so that it is as well not to place it in the hands of those who are not used to making such tests. The factory test should, to my mind, be amply sufficient in most cases. We must obviously have an alternating-current test for the dielectric stress. The stress to which the continuous current subjects the cable is quite different,

Mr. Raphael.

\* *Journal of the Institution of Electrical Engineers*, Vol. 44, p. 25, 1907.

† *Journal of E. E.*, vol. 47, p. 486, 1911.

‡ *Ibid.*, vol. 52, p. 51, 1914.

Mr.  
Kappeler,

and the fact that some observers have found the breakdown voltage with certain cables to be from 3 to 4 times greater with continuous current than with alternating, cannot be taken as fixing this ratio for every cable and every class of fault. For instance, the fault which the author describes as having been broken down successfully with continuous current was produced by flattening the cable. It is quite possible that if he had produced that fault by making a pin-hole in the cable and allowing a small amount of water to be absorbed until the insulation resistance had decreased to about 1 megohm or only slightly less, he would not have broken down that fault with continuous current at all, although he would have been able to do so with twice the working alternating voltage or the alternating voltage plus 10,000. When a repetition of the test for dielectric stress or a breakdown test after laying is absolutely necessary, it can, in the case of comparatively short cables, be carried out with apparatus which can be easily provided in the works, if proper care is taken. In the old days we were satisfied with a couple of step-up transformers with their secondaries in series. That answered very well, and such apparatus has broken down hundreds of faults which withstood the ordinary pressure. Mr. Welbourn has pointed out that this fatigue idea of the author's is wrong, that is to say, the cable does not get a permanent strain; it is either something in the nature of merely a temporary strain or it is a sub-permanent strain, so that if we go through the same cycle of testing for the same time we shall not break the cable down. That being so, the only reason against its repetition when necessary, apart from unskilled testing, is the difficulty of obtaining large apparatus. Of course in very many cases there is no need to test very long cables joined up together. The most satisfactory method of all for testing a cable after laying is one mentioned by Mr. Beaver in his recent paper.<sup>23</sup> Mr. Beaver proposed a cable with a metal sheath a little way under the lead and separated from the latter by a comparatively thin layer of insulation. That layer of insulation is tested and will have an insulation resistance of some megohms per mile if it is all right. If the lead is punctured after laying, or if the cable is seriously flattened, or anything of that sort occurs, the insulation between the test sheath and the lead will partly break down, or break down altogether. Of course that device increases the cost of the cable to a certain extent, because it is necessary to make the test sheath of a certain thickness of metal for mechanical reasons. The Germans have recently shown us, however, a way in which possibly the cost of that sheath may be diminished. Owing to the dearth of copper in Germany, they are using zinc for the conductors of their cables. It is a very poor makeshift, judging by what I have read in the German papers, because new rules and new precautions are constantly being issued telling people how to use such cables, and explaining that if properly used they are not so bad as they really are. It might be quite possible, however, to use zinc wire for such a test sheath, because the conductance does not matter and the thickness of metal to give the necessary mechanical strength could thus be had at a lower cost than with copper wire or strip.

Mr. E. A. WATSON: The results of my experiments, referred to by Mr. Welbourn, have never been published,

<sup>23</sup> *Journal I.E.E.*, vol. 53, p. 57, 1915.

and in a way they were not completely successful. It was an attempt to test a large cable at 150,000 volts with continuous current, using an improved form of electrical influence machine. The ordinary electrical influence machine is constructed of glass plates, tin-foil, and varnish. This was an effort to lift the influence machine out of the realms of the physical laboratory and make an engineering job of it. If one considers the theory of the influence machine, one finds that the output of the machine is limited by the dielectric strength of the air in which it works, and if the dielectric strength of the air could be doubled one could double the output of the machine. If air is compressed, its dielectric strength increases nearly in proportion to the pressure, and if the output obtainable from given cubical contents be calculated it will be found that by employing an air pressure of about 10 atmospheres or 150 lb. per sq. in. it is theoretically possible to obtain an output comparable with that which would be given by a dynamo of the same dimensions. The first step taken to improve the influence machine was therefore to run it in compressed air, and later on nitrogen was tried. The next step was to get a greater amount of active surface in the same cubic space. The ordinary influence machine is sometimes built with two or three or even more plates, but it has a separate set of collector gear and brush gear for every plate, so that in attempting to build a very large machine with a very large number of plates, if the ordinary methods of construction were followed one would get a very unmechanical machine on account of the large amount of brush gear. A construction was therefore adopted which did away with all these different brushes, by connecting the active material on each plate together by axial rods passing through the machine, and these axial rods were brought to a collector on the end of the shaft corresponding more or less to the commutator of a dynamo. The machine in question was designed for an output of  $\frac{1}{2}$  kw. at 150,000 volts. The ordinary influence machine gives generally about 1 watt or, at the most, 2 or 3 watts, so that this was rather an ambitious scheme. The machine had 30 revolving plates each  $12\frac{1}{2}$  in. in diameter, and the metal sectors, instead of being made of tin-foil pasted on glass, were made of sheet brass vulcanized into ebonite. The collector consisted of hardened steel rods screwed into an ebonite disc and joined to these revolving sectors by axial rods passing through the machine. The stator or fixed portion of the machine simply consisted of a number of steel plates with cast-iron distance pieces holding them apart. These plates were built up into units, bolted together, and the units were mounted on ebonite insulators cemented into cast-iron rings, so that all glass or anything of that nature was effectively done away with. The machine was separately excited by a small overhung exciter at the end of the main machine, and this exciter was connected to a needle-point gap outside. By varying the needle-point gap one could control the excitation of the exciter and thereby the output of the main machine. The machine was not completely successful owing to trouble caused by breakdown of the solid insulation, although in other respects it realized all our expectations in the way of output and general performance. When used for testing a length of several miles of concentric cable we got up to 150,000 volts on one occasion for two or three minutes, and we had several runs at 130,000 volts

Mr.  
Watson

for a period of half an hour or so. Eventually, however, the machine broke down from general disintegration, the solid material puncturing everywhere, the punctures in every case showing evidence of a large amount of power behind them and being accompanied by general mechanical disintegration of all the ebonite in the vicinity. The chief reason why the machine failed was, I think, that in attempting to build an influence machine on a large scale we had neglected various precautions which do not come into account in the ordinary small-power machine. The chief fault was that the number of sectors on the rotor was too small and their size too large. Consequently, as they revolved they introduced serious oscillations and surgings of the voltage of the different portions of the machine. The fact that the multiplicity of brush gear common to the ordinary influence machine had been replaced by a collective grouping of the sectors with the use of a single brush, only served to aggravate this fault. There was also some sparking at the brushes due to their not being at exactly the same potential as the oncoming collector segment, although special means had been taken to reduce this difference of potential to a minimum. This sparking set up oscillatory currents in the axial rods and rotor sectors. The amount of power behind the oscillations was comparatively large, and breakdown of the insulation occurred, although the factor of safety against breakdown was nominally about 20 to 1. Some day I hope to have another opportunity of working on the same subject. It is very interesting and has not been worked on by other investigators; and I believe that if another attempt were made to build such a machine for this work it could be done with a much greater degree of success.

(Communicated): There is no question of the importance of being able to test a cable when laid without the necessity for the large and expensive transformers which are required for carrying out the test with alternating current, and on this account the paper is of great value. There are, however, one or two points on which one would like to have a little further information. The author's description of the Abraham-Villard voltmeter is not very clear, and one feels that a drawing or photograph of this instrument would have been a great advantage. In the tests referred to by Mr. Welbourn an electrostatic voltmeter with compressed-air insulation was used, which operated quite satisfactorily and had the advantage of being compact and portable. One would like a little more information as to the ratio given as 2.6 for the relation between the continuous-current and alternating-current breakdown voltages of a cable. There must be a large number of factors which influence this figure, and one would like to have some idea of what these factors were and on what they depended. In air or any dielectric which was not permanently injured by the discharge the ratio would be much less than this, being for a sine wave 1.414. It would probably depend on the relative values of the specific inductive capacity and resistivity of the various wrappings of insulation which go to form the complete cable, and might be very different in the case of a paper-insulated cable compared with one having rubber insulation. It would probably have different values also in the case of graded and ungraded cables. One would like to know also whether the author has found the same breakdown voltages in the case of concentric cables with the inner core positive as with it

negative, since in the case of a wire-stretched in air in a concentric tube the + and - values of the breakdown voltage are not necessarily the same. It is interesting to note that the apparatus does not produce any sensible ripples in the voltage to which the conductor is charged, but one would imagine that it would require rather careful manipulation of the control gear in order to ensure this result, especially while the cable was charging up, as it would apparently be quite easy to excite the transformer to full voltage with the cable nearly dead, in which case some disturbances would surely occur. One would think that some sort of high resistance in the charging circuit would be advisable in order to guard against the production of oscillations, and it is of course possible that some arrangement of this sort is provided.

Mr. J. WARREN: A point in connection with the practical use of such an apparatus as the author has described is the range of the continuous-current test-pressure obtainable, and the method of control, if any, adopted in order to obtain a variable test-pressure. I notice that the author refers to tapings on the extra-high-tension secondary side of the transformer, but I presume other means are provided to vary the pressure uniformly. I hope that in his reply the author will give some information on this point. I have in mind the case of a large system where the voltage of the trunk mains would be much higher than that of the distribution mains; say, 60,000 volts and 6,000 volts respectively. In such a case it would certainly be desirable to have an apparatus which could be utilized for testing all high-pressure mains on the system, i.e. both trunk and distribution mains. This would appear to involve some simple means of controlling and varying the continuous-current test-pressure. Would a transformer of reasonable size for testing the trunk mains be generally of suitable size for testing the distribution mains having a different insulation resistance? I notice that the author refers to a difficulty in connection with the application of the apparatus to the testing of single-core cables; and apparently if the apparatus is to be used more particularly for such purposes it should be equipped with auxiliary condensers in order to utilize the principle of the apparatus to its maximum extent and avoid having a transformer of higher pressure than necessary. The author states casually that in most cases single-core cables are constructed to transmit low-tension current. I think it would be worth while to develop the apparatus, even if it were only used in connection with the testing of such cables, since it is most probable that higher transmission pressures will be attained with single-core cables than with multicore cables. I am at present interested in a very high-pressure transmission system which is being installed in this country and in which single-core cables are to be employed. An important use of the apparatus appears to be in connection with the installation of a new system, possibly a system where the proposed working pressure is higher than that previously adopted and where some uncertainty exists as to the eventual performance of the chosen system of cables and joints. The apparatus enables tests to be carried out as the work on each section proceeds, so that any defects in laying and jointing can be detected and the methods improved if necessary. The cable system when completed could be tested with the apparatus to ensure that the cables and

Mr.  
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joints provide a sufficient factor of safety to withstand both the normal and abnormal pressure rises to which the system is liable. I hardly think the periodic testing of mains is necessary or even desirable once the system has been laid and tried, since the cables and joints will have proved themselves capable of withstanding the working conditions of the system. It appears to me that an independent source of supply forming part of the testing equipment would be very desirable and would enhance the use of the apparatus; and such a supply would be essential if it were intended to use the apparatus during the installation of a system. If an independent generator could be erected on the truck and driven by, say, a small petrol motor without fear of upsetting the electrical sparking contacts, it would be a great advantage. The use of the apparatus would appear to be somewhat complicated, owing to the continuous-current test-pressure varying with the equivalent alternating-current test-pressure and with the length of the cable to be tested; also the apparatus would seem to require rather more than the usual amount of care in order to prevent the cables being damaged during testing. The author refers to a test on a 20-yard length of cable with an artificially produced fault. Is he satisfied that the apparatus would sufficiently burn out a defect anywhere in a 20-mile length of cable so as to enable the fault to be easily located, since at first sight the small power provided would not appear to be sufficient to do this? The question has been raised as to what would be a practical length for the sections of a very high-voltage network. This is largely a question of cost, but in one system in which I am interested it has been decided to divide the 30,000-volt cables into lengths of from two to four miles. In this instance a transformer to test an average length of, say, three miles of those cables would be of the order of 500 k.v.a., and I think the continuous-current testing apparatus would be of some use.

Mr. Sayers.

Mr. H. M. SAYERS: The author and one or two of the speakers have pointed out that the testing of cables by continuous current is a reversion to the oldest methods. The use of continuous current of very many times the working pressure is also a reversion to old methods, because submarine cables in the process of factory testing—and sometimes in the process of testing during laying—were subjected to a pressure from as many as 300 Daniell cells, i.e. approximately 300 volts. The author has left out of the paper one of the great advantages of testing with continuous current instead of alternating current, namely, that during the process of testing with continuous current the actual dielectric resistance of the cable can be measured. The engineer who is responsible for the maintenance of a network of cables is anxious to know the insulation resistance of each particular length of cable from time to time, because the variation of that resistance is an indication to him of the presence or the absence of incipient faults. A particular cable, so long as it is sound, gives an insulation resistance which shows slight variations dependent upon the temperature. If the insulation resistance has decreased from, say, 10 megohms to 1 megohm between successive tests there is a fault somewhere and the engineer takes measures to find out where it is. He does not want to break down the cable, but to find the fault before the cable breaks down. The

usefulness of an insulated sheath for the purpose of detecting a small lead fault or the intrusion of water has been well demonstrated to me many times in the testing of concentric single-phase cables with a normally earthed outer. The outer, insulated for testing purposes, acts as the sheath described by Mr. Raphael; the outer shows a drop of resistance due to a lead fault long before anything is indicated by the inner, and long before the cable is in danger, because the low insulation between the earthed outer and the lead is not in itself a danger, whereas the further penetration of water to the inner would be a serious danger. Such methods, which depend upon the use of fairly high continuous pressures for testing and for localizing, are much better than the use of extra high pressures for breaking down a cable. With regard to acceptance testing by alternating current, I have on several occasions found it advantageous to use a separate engine for the purpose, run at as low a speed and therefore at as low a frequency as would give the pressure required. Reducing the frequency naturally reduces the capacity current of the cable, and therefore the size, weight, and rating of the transformers required for the test.

(Communicated): The measurement of the insulation resistance of a cable referred to in my remarks is most conveniently made by observing the rate of fall of potential after the disconnection of the pressure apparatus. The electrostatic instrument described as part of the apparatus should serve for this observation. As the rate of fall is independent of the length of the cable, provided that the ratio of capacity and insulation resistance is uniform, this observation affords a ready means of comparison of the condition of similar cables of different length, or of different portions of one feeder. For the records of periodic tests it would be sufficient to observe the time taken for the potential to fall between definite values. Unsteadiness of the rate of fall will also give indications of small leakages, especially such as are due to dust and moisture on the switchgear, etc., or to very small faults in joint boxes and transformers. Following testing practice with low pressures, the result of testing with both polarities applied to the conductor may perhaps be found to give valuable indications. This can only be settled by experiment; and the author may perhaps be able to state in his written reply to the discussion whether anything has been done in this direction. With moderate pressures, the osmosis effect is sometimes masked by the evolution of hydrogen at the surface of the conductor where the fault is a very small crack, or where little moisture is present. From Mr. Evershed's results it is probable that the endosmosis effect will overpower the evolution of hydrogen, and that the lower resistance of a moisture fault with negative polarity of the conductor will be more marked and persistent with high testing pressure than with low.

Mr. P. ROSLING: In regard to the author's statement that there is no definite relation between the insulation resistance and the dielectric strength, there is a relation between the breakdown test and the temperature. The half-hour test that Mr. Trotter mentioned introduces the temperature question. It may be that by testing a cable at a considerably higher pressure than the working pressure, we introduce a factor which really does not arise in practice, because by maintaining the extra high pressure for half an hour we obtain a temperature in the dielectric

Mr. Rosling.

that we shall not get in practice through a surge or similar effect. The author says that in testing the cable by suddenly increasing the voltage, as against raising it minute by minute, the difference in breakdown pressure is as 2 to 1. I take it that this is partly caused by an increase in the temperature of the dielectric itself as well as by the fatigue caused by the time the pressure is on. We have not heard very much from the users of cables as to the desirability of having continuous-current tests. From the makers' point of view it seems to be a reasonable proposition, more especially as after a cable is laid the trouble most likely to occur is through moisture entering at the ends or in the boxes, and it seems to me that the continuous-current test would indicate any likely danger from moisture—by collecting the molecules of moisture together—better than the alternating-current test would. One or two speakers have mentioned the large plant required for testing with alternating current. I think that is not so much due to the use of alternating current as to users specifying that the length between sub-stations shall be tested in one piece. Taking a 20-mile length of 20,000-volt cable with 10 joints to the mile, that is to say 200 joints in all, engineers want the whole length tested at one time. It seems reasonable to me for such a cable to be tested in four sections, or even more; for one can take such special precautions to have those three or more final coupling joints particularly carefully made, that the engineer would know that if these joints withstood the ordinary working pressure, they would withstand equally well an extra pressure test similar to that to which the remainder of the joints had been subjected.

The PRESIDENT: The paper makes special reference to investigations made on the Continent, and omits, as pointed out by Mr. Welbourn, any reference to a great deal of work that has been done in this country. In Great Britain we have a habit of decrying ourselves and saying little about what we are doing, and the world outside often takes us at our own valuation. There are certain statements in this paper that imply that British practice is crude and unsatisfactory. For instance, on page 610 the statement is made that "By employing continuous current, supply authorities can therefore as often as desired repeat their tests without raising the opposition of the cable manufacturers." It looks from that as if British cable manufacturers and the supply authorities were in a perpetual state of friction, whereas from my experience nothing of the kind occurs. British cable manufacturers lead the world, are not behind their Continental competitors, and are prepared to fulfil any reasonable specification. I have never had any opposition from cable manufacturers in regard to cable testing. Now let us analyse what this testing is. First of all there is the test at the cable-makers' works, that is, a test of the cable. If the cable is to be used for alternating current, the test is carried out with alternating current, and I think it is necessary that such tests should continue to be made with alternating current. When the cable is laid, however, an altogether different class of test is required. What we require then is really to test the joints. The cables are built with a large factor of safety over and above the working pressure, and they must necessarily have a large factor of safety, because, although they may operate at 10,000 volts, surges in the supply pressure may cause the voltage to exceed the

normal pressure considerably. It is necessary, therefore, to test the cables in the works to see that they have a large margin of safety. When the cables are laid the joints have to be tested, and it is really the work either of the contractor or of the company that has laid the cable to see that the joints are sound. Up to now, working with extra-high-pressure systems of comparatively moderate pressures, little difficulty has been experienced in testing the joints with alternating current. I have in mind one length of 18 miles of 10,000-volt cable. By grouping the transformers at a suitable point, a length of some five miles was the greatest that had to be tested at one time, and little difficulty has arisen. When we come to higher pressures the problem is more difficult. In one system now being erected for me the working pressure is 30,000 volts, and I welcome a paper of this kind which shows us what the possibilities are with regard to using continuous current not to test the cable but to test the joints. Then there is another statement on page 610 to which I should like to refer:—"It results from this, and it is at once very important and very unfortunate from the point of view of supply authorities, that manufacturers energetically oppose an alternating-pressure test higher than the working pressure being repeated on cables for which they have undertaken the guarantee." That would seem to indicate that when these cables are once laid the supply authorities have to dry-nurse their systems. In my experience cables are bought and pass these tests, and once they have done so they are put to work and are left at work. We have not to keep on testing them. The cables supplied by British manufacturers at all events are reliable, and it is quite a misconception to think that questions of this kind arise. If a fault does take place on a cable system, almost universally it is at a joint; that joint is re-made and the cable is re-tested before being put to work, and then it continues in use for years before there is a repetition of such a fault. That is my experience. The author continues: "I say that this is unfortunate from the point of view of supply authorities, for the engineers responsible for these undertakings naturally wish to be able in some way to ascertain the condition of their networks by pressure tests performed either at periodic intervals or whenever an accident occurs." I agree that they have to do it when the accident occurs, but in my experience of British cables it is a very remote contingency, and I think it is a great pity that in this paper, which is written from a British point of view, we have it implied that there are all these difficulties. The paper seems to imply that English manufacturers, instead of leading the way, are crawling behind their Continental competitors, which is a quite erroneous view.

Mr. J. F. WATSON (*communicated*): The apparatus described in the paper appears to be very well thought out, and it has been reduced to such a size as to render it quite portable. With reference to the comparative breakdown effect of continuous current as against alternating current given in the Appendix on page 615, I have tested a considerable amount of cable at pressures up to 110 kilovolts (continuous current), and have obtained figures on paper-insulated cables of much the same order as those given by the author, though, perhaps, the ratio obtained was a trifle higher, but I think it would be a mistake to assume that this ratio will hold good for all classes of

Mr. Sparks.

Mr. Watson.

Mr.  
Watson

dielectrics. There is another point which has not been raised in the discussion, namely, the best means of discharging the cable at the conclusion of the pressure tests. If the conductors under pressure are connected together with a metallic conductor of low resistance, it appears to me that an abnormal potential gradient would be put upon the inner layers of the dielectric, and must result in their perforation. I suggest that the apparatus described should be provided with a suitable means of gradually reducing the voltage between the conductors under test. The author puts forward this system of continuous-current testing as a means of carrying out a pressure test on great lengths of high-pressure cables when laid: he does not suggest that a continuous-current test should be applied to the drum lengths of cables when completed at the factory. He further points out that dielectric loss when testing with continuous current is practically non-existent, and for this reason alone it could not be entertained for testing in a factory. On all these points I fully concur. In conclusion I would repeat that I think great care ought to be exercised in discharging the cable at the termination of the pressure test, as this is of vital importance.

Mr.  
Record

Mr. O. L. RECORD (*in reply*): I am very sorry that the President and Mr. Welbourn have read into the paper inferences and reflections on cable makers, particularly British cable makers, which were never intended, nor can I admit that such an interpretation was justified. Though I did not state it in so many words, I should have thought it was clear from a perusal of the paper (cf. p. 609, col. 2, par. 1) and from the fact that there is as a rule little difficulty in making alternating-current tests on 6,000-volt or 11,000-volt cables after laying, that cables for voltages beyond those which ordinarily occur, such as for 30,000, 40,000, or even higher voltages, were referred to. If this is borne in mind when reading the fourth paragraph in the first column on page 610 to which the President referred, it will at once be evident, I think, that it cannot reflect either on British cable makers themselves or on their relations with supply authorities, as with very few exceptions no cables for such voltages have been installed in this country. It is evident this paragraph can only apply to those who have manufactured and installed such cables, as Mr. Welbourn rightly assumed. These latter have found it necessary (and they do not consider it any reflection on their manufacturing ability), in the case of very high-tension cables\* such as these, to take precautions in the matter of alternating-pressure testing after laying, owing to the fact that it is a practical impossibility to have anything like the same margin of safety in these cases as with, say, 6,000- or 11,000-volt cables, whilst the danger from surges, etc., due to testing without proper precautions is far greater. It is quite possible that British manufacturers will find it necessary to take similar precautions in such cases; with 6,000- or 11,000-volt cables the question does not arise, as there is such a large margin of safety that double the working pressure would never come up to the value O A described in Fig. 1. That such very high-tension cables are not installed to any extent in this country is simply due to the fact that up to the present there has been no

call for such cables, and not to the inability of British manufacturers to produce them. The President later on interprets the fourth paragraph of column 1, page 610, as indicating "that when these cables are once laid the supply authorities have to dry-nurse their systems." Now, however good the cables may be in themselves, there are always a number of extraneous causes which may produce trouble, and whilst I admit that breakdowns are rare, they do occur, and in order to anticipate them the majority of cable systems are tested periodically for insulation resistance. If now a high-tension test could be made on these occasions with little extra trouble and without any danger of injuring the cables, I submit that it would be an advantage. It seems rather extravagant to interpret this clause as implying the necessity of frequent tests, owing to the imminent danger of or as the result of frequent breakdowns. The words "as often as desired" merely indicate the harmless nature of the continuous-current pressure test.

Mr. Welbourn enters a protest that I have not referred to other methods which have been proposed and used for the continuous-current testing of cables, and mentions the excellent work of Mr. E. A. Watson. Whilst I highly appreciate the value of this work, I have not referred to it for the reason that it is not relevant to the subject of the paper. Of the three papers cited, one deals with "A Simple Method of Measuring Sparking Voltages," the second with "The Dielectric Strength of Compressed Air," and the third with the "Losses off Transmission Lines due to Brush Discharge." That part of Mr. Watson's work which is relevant, viz. that dealing with its influence machine, has not been published, as he himself points out (see p. 618), though it was briefly referred to by Mr. Highfield in his paper on "The Transmission of Electrical Energy by Direct Current on the Series System."\* Mr. Welbourn points out that I have not made it quite clear that one should differentiate between the tests which are carried out on cables. I quite agree with him that where cables are to be used for alternating-current transmission, the tests at the works should be made with alternating current, and I would not suggest that they should be superseded by continuous-current tests. The apparatus described is primarily intended for tests after laying.

Mr. Welbourn mentions that we now have 33,000-volt cables, and he considers that 50,000-volt 3-core cables will be used in this country in the near future. I think I am right in saying that a short length of 3-core cable for a working pressure of 65,000 volts was laid in Nancy towards the end of 1913 for the Compagnie Lorraine d'Electricité. I cannot pass over the statement attributed to me that "if we get a breakdown under continuous current with practically no power behind it, we merely puncture the insulation and we may or may not be able to burn the fault out," as it gives quite a wrong impression. I merely queried the possibility of being able to burn out a fault with apparatus of such small power, in order to adduce evidence to show that it can be done. I am sorry I have not the oscillograph records to which Mr. Welbourn referred. The tests were made on a number of lengths of cable of different capacities, and the maximum values were found to be as stated in the paper.

In connection with Fig. 1 Mr. Welbourn considers that

\* Since cables for as low a voltage as 3,300 come in the category of extra-high-tension cables in the British standard specification, some new expression is necessary for specifying cables for, say, 20,000 to 100,000 volts.

\* *Journal I.E.E.*, vol. 40, p. 852, 1912.

I should have gained more sympathy from cable makers if I had paid some tribute to the work on similar lines which has been done in England, and then he refers to Sir John Snell's book on "Distribution of Electrical Energy" for an exactly similar curve prepared by him and his colleagues to years ago, namely, Fig. 4, page 92. In the copy of this work which I have by me this figure gives four curves connecting the temperature rise with time, with insulation resistance, with copper resistance, and with capacity respectively. I cannot find anywhere in the book a curve connecting breakdown voltage with time. It occurred to me that perhaps there was more than one edition, but I understand that this is not so. He does not agree that the curve in Fig. 1 indicates dielectric fatigue. I do not consider, however, that the figures he gives in any way prove the contrary. Everything depends upon the values of the voltage and the time of application of the same, that is to say the position on the curve of the breakdown point, for Mr. Rayner\* found as a result of his experiments on insulating materials that whereas the application of a high voltage for a short period would not do any permanent injury, the application of a lower voltage for a correspondingly longer period might reduce the dielectric strength considerably. It would look as if the length of time 50,000 volts could be applied was too short to develop fatigue in the cable; no doubt if 40,000 or 45,000 volts had been applied over a correspondingly longer period, the results obtained would have been very different.

Mr. Trotter refers to a time curve similar to Fig. 1 in Mr. Evershed's paper.† These curves (there are two) connect charging current under a continuous pressure with time, which is rather a different matter, though the shape of the curves is similar. He mentioned subsequently that though I stated there was no relation between insulation resistance and dielectric strength, I later on assumed that there was a relation. This is hardly correct. It is true that I stated shortly afterwards that "the present state of knowledge does not permit us to say there is no relation," but I immediately gave an account of various phenomena which tend to indicate that there is no relation, even if they do not absolutely prove it. His assumption that the cable referred to at the top of the second column on page 609 would be for a working pressure of 30,000 volts is quite correct.

Mr. Raphael also referred to Mr. Evershed's paper. I quite agree with him that this paper and the discussion upon it contains a wealth of valuable information, but, as Mr. Evershed explained, at the time the paper was written he had only been able to investigate thoroughly the first part of the typical voltage-resistance curve and consequently only dealt with that; the investigation of the second or breakdown part of the curve was only in a preliminary stage. The relation between breakdown voltage and time is therefore not touched upon, nor the relative values of continuous and alternating breakdown pressures, which are the two outstanding points in connection with this paper. Nor has Mr. Rayner investigated the relative effects of alternating and continuous currents on insulating materials, all his tests being made with

alternating current. I was very glad to hear that Mr. Raphael agrees that the alternating-current pressure test should not be repeated. Apart from the reasons which he indicates, it is certainly injurious, and whilst the injury may be negligible with cables up to 11,000 or even 20,000 volts, it is a matter which has to be reckoned with in the case of very high pressures.

With regard to the ratio between alternating and continuous pressures, the most recent investigation was that carried out by Dr. Lichtenstein and described in the Appendix. Allowing for errors in readings, the figures show that for a particular insulating material the ratio is constant; and furthermore, that the ratio is practically the same in the case of paper and rubber-insulated cables. There would be little difficulty in breaking down with the apparatus a fault such as Mr. Raphael describes. As Mr. Welbourn points out, a continuous-current test will deal with moisture troubles more readily than an alternating-current test, whilst the subsequent discharge through the fault would assist breakdown. The capacity of the transformer has been standardized at 3 kw. as a result of experience obtained in practice, as this was found capable of dealing with all ordinary faults, but in very exceptional cases there is no reason why it should not be of larger capacity. It must, however, be borne in mind that 3 kw. is actual effective power; it has not to be reduced to a small fraction of its value on account of a low power factor as in the case of alternating current. The power is therefore not so small as would at first appear from a comparison with the k.v.a. capacity of the alternating-current testing transformer. The sheath proposed by Mr. Beaver appears to be a very good thing, and if engineers are satisfied with this method of testing and adopt it, there will be no need either for this apparatus or for the ordinary alternating-current testing apparatus. A drawback to it, however, is the extra cost involved, as Mr. Raphael points out.

I was very much interested in the description Mr. Watson gave of his influence machine. This was, I understand, the machine used by Mr. Highfield to test the 100,000-volt cables installed on the Thury system of the Metropolitan Electric Supply Company.

In reply to Mr. E. A. Watson's communicated remarks, I have illustrations and blue-prints of the Abraham-Villard voltmeter, but unfortunately they were not suitable for reproduction in the paper. It is quite reasonable to expect that the ratio between continuous-current and alternating-current breakdown voltages would vary with the nature of the insulating material; the experiments carried out by Dr. Lichtenstein, however, do not show very much variation in the case of paper-insulated and rubber-insulated cables. No experiments have been made with concentric cables, as this type of cable is seldom used for the very high pressures indicated in the paper. No special care is required in order to prevent voltage ripples occurring when charging up the cable. The full potential of the transformer is at once put on to the contact maker, although the potential of the cable itself only rises gradually to its full value, as explained in the paper.

Mr. Warren raises the question of the range of test pressure and the method of control adopted. For varying the pressure there is a regulating resistance on the control panel connected with the primary side of the transformer,

\* "High-voltage Tests and Energy Losses on Insulating Materials,"

† *Journal I.E.E.*, vol. 49, p. 3, 1912.

‡ *Journal I.E.E.*, vol. 52, p. 51, 1914.

Mr. Rosent.

which will give as large a range of voltage as is ordinarily required. In a case such as that instanced where it is required to test cables of very different voltages, it would be necessary to have, in addition, tapings on the transformer. A transformer of the same capacity would be suitable for both the trunk and distributing mains, but on account of the high voltage of the former, the contact maker would consist of two entirely separate discs each with only two brushes, so as to prevent flashing over. Mr. Warren quite rightly points out that it is always possible to obtain the full pressure of the apparatus in the case of single-core cables by employing the auxiliary condensers, and I quite agree with him that this is an important point since higher pressures are more likely to be attained in the future with single-core than with multi-core cables. With regard to the question of fitting the apparatus with a separate source of energy so as to make it self-contained, I have described in the Appendix the apparatus in use by Messrs. Siemens Schukert in which this idea has been embodied. In addition to the hand-cart carrying the contact maker, transformer, etc., as described in the paper, there is a second cart carrying a small petrol-driven alternator for supplying the necessary low-tension current to the transformer. As there pointed out, it is then possible to complete the testing of the cables before the central station is ready to supply power. I do not quite follow the reasons put forward why the use of the apparatus should be complicated. It is designed for a testing voltage dependent on the normal working pressure and the percentage above normal at which it is desired to test, and the length of the cable to be tested will not affect this voltage. The apparatus is no more complicated to use, nor does it require greater care in handling than the corresponding alternating-current testing equipment. I am quite satisfied that it would sufficiently burn out a defect on a 20-mile length of cable as to enable the fault to be easily located; for, as pointed out above, the power is really not so small relatively as would at first sight appear. Nevertheless, a transformer of a larger capacity can always be supplied where the conditions demand it.

I must thank Mr. Sayers for pointing out another advantage of continuous-current testing, namely, the possibility of measuring the actual dielectric resistance

of the cable. Up to the present no experiments have been made to ascertain the effect of change of polarity. Mr. Rosent.

Mr. Rosling was inclined to think that the breakdown voltage did vary with the temperature. Of course if the temperature is raised as the result of the losses in the dielectric, I quite agree; but if the temperature is varied independently, it will be found to have practically no effect on the breakdown voltage, provided that the temperature is not raised to such a point as to alter the constituency of the insulating material. I must disclaim the statement "that in testing the cable by suddenly increasing the voltage, as against raising it minute by minute, the difference in breakdown pressure is as 2 to 1," though it is possibly correct. Fig. 1 shows how much greater a voltage can be applied instantaneously than for a period, the reduction in breakdown voltage in the latter case being due to the heating up of the dielectric resulting from the prolonged application of the pressure. I therefore quite agree with Mr. Rosling that in testing a cable for half an hour at a pressure considerably above the working pressure, we may be introducing a factor which does not arise in practice, where any pressure-rises are more or less instantaneous. Finally, I would add that this apparatus was designed for continuous-current testing, as in some instances it was found impossible in the case of the very high voltages which are being adopted on the Continent to carry out alternating-current tests after laying. With the voltages at present prevailing in this country, there are but few cases where it is not possible and fairly easy to carry out such tests, but I have no doubt that, with the high voltages which will surely prevail in the near future, it will be found absolutely necessary to employ continuous current for the purpose.

I have dealt with the President's remarks at the beginning of my reply.

In reply to Mr. J. F. Watson, I quite agree that great care must be exercised in discharging the cable at the termination of the pressure test and that it would be dangerous to do so through a metallic conductor of low resistance. With the Delon apparatus this question is very simply taken care of; all that it is necessary to do after a test has been completed is to continue to run the contact maker whilst gradually reducing the transformer voltage, thus allowing the cable gradually to discharge.

#### WESTERN LOCAL SECTION, 7 FEBRUARY, 1916.

Mr. Proctor. Mr. C. F. PROCTOR: I am rather curious to know whether any sparking occurs in collecting the positive and negative current, which it practically amounts to, in the machine.

Mr. Tremain. Mr. F. TREMAIN: It would be interesting to know what alternative methods have been adopted for making continuous-current high-voltage tests; the author appears to confine himself to the Delon apparatus.

Mr. Allan. Mr. C. T. ALLAN: I should like to know if the author thinks the Delon method would be of use for charging cables when faults are being located by the capacity method. Normally we use 500 volts continuous current for charging the cable, but a higher voltage might be of some value for obtaining more accurate figures. Will the author also say what results he would expect to obtain

when testing long lengths of feeder, consisting partly of cable and partly of overhead line, with the usual substation feeder switchgear and busbars in circuit as well? Mr. Allan

Mr. O. L. RECORD (*in reply*): In reply to Mr. Proctor, the brushes do not actually make contact with the revolving conductor, the circuit being completed through a short spark; the gap is about  $\frac{1}{2}$  mm. Mr. Record.

Mr. Tremain would like to have particulars of some alternative methods which have been adopted for making continuous-current high-voltage tests. Mr. Highfield used for the purpose a special influence machine of the Voss type designed by Mr. E. A. Watson and described by him in his contribution to the discussion (page 618). This machine was used for testing the 100,000-volt mains on the Thury system of the Metropolitan Electric Supply

Company and was referred to by Mr. Highfield in his description of this system.\* Similarly, at Lyons the cables in connection with the Moutiers-Lyons high-tension continuous-current transmission were maintained at a continuous pressure of 300,000 volts by means of a friction machine having an output of only a few hundred watts.† An ordinary Ruhmkorff coil has also been used for the purpose, but in this case electric valves have to be included

\* *International E. E. F.*, vol. 20, p. 818, 1913.

† *Electric Age*, 51, p. 967, 1913.

in the circuit to prevent the cable discharging through the coil as fast as it is charged. An account of this method has been given by M. Picou in the *Bulletin de la Société Internationale des Electriciens*, vol. 10, p. 620, 1910.

In reply to Mr. Allan, it would certainly be an advantage to use the Delon apparatus for charging up cables when localizing faults by the capacity method. It is not possible, however, to charge up a system comprising overhead lines with the apparatus, as it has been found that the latter will not maintain the charge.

Mr.  
Record.

### MANCHESTER LOCAL SECTION, 8 FEBRUARY, 1916.

Mr. C. J. BEAVER: There are a few points on which it would be interesting to have the author's reply. In the first place, taking it on the broadest grounds, it is well known that the distribution of stress is quite different with continuous current from what it is with alternating current; it depends on different factors, viz. insulation resistance in the former case, and capacity in the latter, and therefore the effects will be quite different. With reference to the object of testing cables after laying, I think we all agree it is a matter not so much of verifying the dielectric qualities of the insulation, which have been already proved in the factory, as to ensure that any damage incurred in laying does not go undetected. On the first page the author says there is no relation between the dielectric strength and the insulation resistance. This may be agreed to as an abstract statement, but I think it is not quite correct to apply it to the case of a given cable under check-test conditions. In a cable having a dielectric of given dimensions we get a certain value of insulation resistance, which at a given temperature is constant; and the same remark applies to its dielectric strength. For check-test purposes an appreciable lowering of insulation resistance will indicate a corresponding alteration in dielectric strength of that particular cable, because the former will be due to some damaging or deteriorating influence. With regard to the weight of the testing apparatus, which is referred to in the paper as a disadvantage of the alternating-current method of testing, there is not as much detail as one would like for the purpose of making a comparison with the Delon apparatus. I see no mention in the paper of the influence which the voltage of the transformer has on the weight of the apparatus. I think it would be fairly appreciable. It is pointed out from certain results given in the Appendix that the equivalent continuous-current value is 2·53 times the alternating-current value. The voltage given by the condensers is 2·8 times the alternating voltage of the transformer. It follows that the voltage of the transformer would have to be about 90 per cent of that of the corresponding transformer for alternating-current testing. Therefore the sole advantage as regards size and weight of the transformer, is that it has to be designed for only a small current. Dimensions which are contingent on insulation requirements for the high voltage belong equally to the two cases. The next point is the fatigue of the dielectric. It does not enter at all into the testing of modern cables. At any rate sound dielectrics are not affected by pressures up to several times the working pressure; and the factors of safety which are nowadays employed ensure that the dielectrics are far removed from any effects of that kind.

Under the heading "Advantages of Testing with Continuous Current after Laying" the author makes further reference to this matter. He says observations made in the case of continuous currents have not shown any of the phenomena of fatigue. That raises the question as to the nature of this fatigue. I think most people will agree it can be nothing else than the reaching of the limit of disruptive voltage of some component of the dielectric. The fatigue stage must therefore be a long way removed from any effect that can be brought about by such voltages as are likely to be applied to cables under working conditions. The remark on page 610 that manufacturers energetically oppose the repeated application to cables for which they have undertaken a guarantee, of an alternating pressure test higher than the working pressure, must refer to the early years of the industry. I can understand a manufacturer showing a disinclination to take the responsibility for a cable which is suffering from things over which he has no control, but otherwise I do not see that it would interest him very much whether it is tested at twice the working pressure or how often this is done. I think perhaps the most important factor in connection with this continuous-current apparatus is the question whether it will satisfactorily burn out faults. Some evidence is given on page 614 that faults produced by maltreating a cable with a hammer can be carbonized and ultimately broken down, but I think one would get an altogether different set of conditions with a fault due to moisture. For instance, imagine a moist patch in a paper-insulated cable. The mechanism of breakdown is as follows: There is first a general leakage through the wet patch; then a selective action of some accidental kind whereby a path is selected through which the current density is greater than in the surrounding bulk of wet material; and then more or less quickly, according to the power available and the amount of current that can be passed through the said path, it dries up, heats, and chars. I think everybody who has had anything to do with testing wet cables will know that they are extremely difficult to break down; the more waterlogged they are, the more difficult it becomes. I should like the author to tell us if he has had any experience of that type of fault with the Delon apparatus.

Professor E. W. MARCHANT: The relationship which exists between the breakdown strength of material tested by continuous current and by alternating current has always seemed to me to be one of the most remarkable phenomena met with in electrical work. If we have a cable with a non-uniform dielectric we shall have an

Professor  
Marchant.

Discussion  
March 1914.

entirely different distribution of stress in the two cases: in the case of continuous current it will depend upon the specific resistance of the material, whilst with alternating current it will depend upon the specific inductive capacities. It seems to me that this is one reason why the method of testing by continuous current cannot be regarded as altogether satisfactory. Although the author has given us a ratio between the strength of dielectrics for continuous and alternating currents, I do not think one is justified in assuming this ratio to be a fixed quantity. Then I come to the question of fatigue. That is a subject which deserves a great deal more consideration than it has received, and I regret that the author has not given us any figures. Some years ago a number of tests were made in my laboratory by Mr. Holtum\* on the dielectric strength of ebonite, the idea being to determine the amount of fatigue. We used a high pressure which lasted for a comparatively short time: the actual conditions were that a 50-cycle current was applied for 1/10 second. A special switch was made so that the pressure could be applied for this definite time and be used as a sort of gauge of the strength of the dielectric. Then, in order to see whether there was fatigue, we applied another pressure from another machine to the dielectric. We had a good deal of trouble in deciding on the best dielectric to use, as we wanted to get something which we could depend upon, and we were finally driven to try ebonite. In one series of tests it was found that ebonite about 0.5 mm. thick broke after a pressure of 16 kilovolts had been applied for a considerable time. An alternating pressure having a maximum value of 13 kilovolts was applied for about 4½ hours, after which the material broke down at 15.2 kilovolts. That seems to indicate that the amount of fatigue in ebonite is extremely small. Further, even when the auxiliary pressure applied was as much as 95 per cent of the actual ultimate breakdown pressure, we were unable to observe a fatigue of more than a few per cent. I have given these figures because I think they have an interesting bearing upon the question of fatigue. I think the fatigue referred to by Mr. Record is due to an entirely different cause, namely, heating, and not dielectric strain. Mr. Rayner showed in his tests that when we get very near the point of breakdown of a cable, the temperature of the dielectric rises suddenly, there is a great increase in the consumption of power, and the breakdown occurs immediately afterwards. We were trying to find whether there was any of what might be called "mechanical fatigue," and the tests certainly failed to show it. I should like to refer to the method of applying the continuous-current test. Mr. Watson worked in my laboratory some four or five years ago on the production of high-tension continuous currents, and devised a machine which was used for testing cables in London. It was a Wimshurst machine, but a real engineering job. I have a number of curves here which were obtained from this machine in which he reached a pressure of 150,000 volts continuous current, and an output of 4.5 milliamperes. Mr. Watson also devised an instrument for measuring pressures. Many years ago in some experiments in which I was engaged I used a voltmeter intended to read to 250,000 volts, though we never actually reached more than 100,000 volts on it. This instrument was about 4 ft. in diameter and 6 ft. high, and was made of

course in the early days of high-tension measurement. Mr. Watson's instrument, though not intended to read so high a pressure, was only 1 ft. in diameter, the moving parts being arranged in a chamber filled with compressed air at 200 lb. per sq. in. pressure. The motion of the needle was observed by reflecting the light from a small lamp through a window at the front of the instrument on to a semi-transparent scale. It was calibrated to read to 100,000 volts and worked extremely well.

Mr. H. A. RATCLIFF: The author makes out a good case for the testing of cables with continuous pressure after laying, and certainly the method advocated possesses many advantages so far as convenience is concerned, but it hardly meets the requirements of a test under working conditions on alternating-current cables. It appears to be somewhat the equivalent of testing a bridge with a "static" instead of a "live" load. The application of an excess alternating pressure at the working frequency is undoubtedly the correct method of testing high-tension alternating-current cables before they are put into commission; and where possible before applying the excess pressure it might be advisable to warm up the cables for several hours by circulating through them the maximum load current which they will have to carry. This could easily be done by means of a suitable low-voltage transformer. Any test which ignores the effect of the dielectric losses is necessarily incomplete. I agree with the author that there is no definite relationship between "dielectric strength" and "insulation resistance," and indeed judging from the results of recent research it appears to be rather doubtful whether there is any direct connection at all between these two properties of an insulating material. Mr. Evershed in his paper\* suggested that insulation resistance was largely dependent upon the occluded moisture in a material. The statement that "at all ordinary temperatures the voltage which will produce a breakdown does not vary much," requires some qualification, as it is not quite clear what is meant by "ordinary temperature." Certainly the dielectric losses increase appreciably with increase of temperature, and the effect of such increased losses is to reduce the dielectric strength of the material under test. It is no doubt difficult to obtain consistent and reliable comparative test results on sheets of insulating material; but the difficulties should disappear to a large extent when the tests are made on several lengths of cable. The reason for this is that the insulation on a paper-covered cable is built up in layers, and consequently there is a sort of diversity factor effect, since the weak spots in the several layers are not likely to coincide. Unfortunately this advantage may be discounted to some extent by the variations in the potential gradient. Insulation resistance, or excess pressure tests, by themselves are insufficient, and in future all tests of any value will include accurate measurements of the actual dielectric losses by means of suitable wattmeters. In the case of tests on sample lengths of cable at the manufacturers' works, the pressure should be applied for several hours, and if possible a superposed low-voltage current equal to the maximum the cables will ever have to carry should be passed through the conductors. All tests should of course be made with the normal working frequency. It is now generally recognized that a high insulation resist-

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Mr. Ratcliff

\* Journal I.E.E., vol. 50, p. 755, 1913.

\* Journal I.E.E., vol. 52, p. 51, 1914.

ance is not necessarily an attribute of a good high-tension cable; nevertheless, for one essentially practical reason it is a distinct advantage if the insulation resistance of the cables is high, and that is because the detection and location of leaky joints and fittings is thereby greatly facilitated. The author perhaps rather magnifies the difficulties of testing with alternating pressure. The testing of 12 miles of cable at a pressure of 40,000 volts would certainly never be undertaken with a portable equipment, but would be done from the generating station, in which, presumably, suitable plant for the purpose would be installed. Tests after laying are usually made on lengths of about 1 mile, so that any defects are as a rule quickly located; and then after all joints have been made, excess pressure on the full length is applied at the generating station or sub-station before the cable is put into commission. Such a final test is required by the Board of Trade Regulations, and, despite the "energetic opposition" of the cable manufacturers, is likely to be repeated on many subsequent occasions. Fig. 1 shows very clearly a well-known effect, and in my opinion the difference between Figs. 1 and 2 serves to emphasize the importance of testing with alternating pressure at the working frequency. I cannot see how a continuous or static pressure can ever be regarded as the equivalent of an alternating one, and the comparison becomes more unsound when it is expressed in numerical terms without any reference to the frequency or to the nature of the material under test.

Mr. F. FERNIE: I do not wish to say that Fig. 1 is never true, but it is not true always or all the time. In testing some paper-insulated cables lately I wanted to put as high a pressure on them as possible without breaking them down, and in one case I found the cable broke down when a pressure of 91·5 kilovolts was applied. Afterwards I applied 90 kilovolts to a different part of the same cable for some hours—in fact until its temperature became constant—without breaking it down. The pressure was put on again and steadily increased until the cable broke down at 91·5 kilovolts. Other cables tested at the same time gave similar results. Similarly the statement as to the breakdown voltage decreasing as the frequency increases is not always true for all cables; at any rate it is not true for frequencies below 100. If there is any decrease it is very small, certainly under 5 per cent. Nearly all statements about dielectrics should be accepted as true rather for a specimen than for a substance. The statement on page 610 that manufacturers energetically oppose the repetition of an alternating pressure test higher than the working pressure, on cables for which they have undertaken the guarantee, appears really surprising in view of the high factor of safety employed by most British firms. I should like to ask the author whether this is a common experience or only an isolated case. On page 609 the author says that when a cable is being laid it is often subjected to damage. From my own experience I should be inclined to substitute the word "never" for "often." With regard to the ratio of alternating and continuous pressures on page 615, I should expect to find different factors for apparently similar cables if they were made by different people. Finally, I would ask the author whether he has experienced any trouble with the condensers which he proposes to use.

Professor A. B. FIELD: The considerable difference of stress withstood by the insulation in an alternating voltage test, as compared with a continuous-current one, immediately suggests an analogy to the effects obtained with a tensile test-bar. For instance, in the case of some grades of steel we find that the stress which will break the material, when frequently applied alternately as tension and compression, amounts to about one-third of the steadily maintained stress that will only just break it. Fig. 1 in the paper represents in a general way the effect that one would expect to get from an ordinary elastic test. In such cases we may maintain for a long period without fracture a stress very near to the ultimate steady breaking stress; but if such stress, or even a lower one, be removed and then renewed slowly several times, the specimen fractures after a few applications. I should like to ask the author whether the analogy holds here, too, in the case of the insulation test. Professor Marchant has touched on the same subject, and has given us some data of tests made by him to determine the fatigue of ebonite. If I understand him correctly, he maintained a steady continuous-current pressure for a number of hours, and then increased it to ascertain the breakdown point. On the other hand, in the electrical test analogous with that of the above mentioned test-bar, we should rather apply the continuous-current pressure test and remove it, repeating the same test several times, to observe a possible fatigue. In other words, reverting to the mechanical case, a steel that will just break with a stress of 65,000 lb. per sq. in. will maintain 65,000 lb. continuously for years; but, nevertheless, this lower stress will have permanently changed the material to some extent, as is evinced by one or two removals and re-applications of the stress. The question then is, whether the dielectric material is similarly changed at all by an application of stress near the breaking point. It would also be interesting to hear whether the same approximate ratio of alternating to continuous puncture test holds in the case of the damaged portion of the cable as for the good insulation, and for a failure by breakdown over a creepage surface as by direct puncture. In considering the value of the author's methods of cable-testing, we must place much importance upon Professor Marchant's observation that the stress distribution depends upon quite different properties in the case of the continuous current as compared with the alternating-current application. If the author's figures for the ratio of these pressures depend upon this feature directly, the analogy with the elastic case will disappear. If, however, the author's figures are at all representative for a flat uniform material, it will stand.

Mr. H. D. SYMONS: A test to determine the soundness of the insulation of high-voltage cables and electrical machinery without either permanently damaging the dielectric or even subjecting it to the risk of damage would be extremely useful, and from this point of view the Delon apparatus is of considerable interest. So far as high-voltage alternating-current tests, however, are concerned, my experience confirms the results obtained by Professor Marchant with ebonite. The tests made on thin sheets of ebonite, taking into consideration the variation that always exists with dielectric-strength tests, showed little if any fatigue, and my experience shows that

Mr.  
Symons

this is always the case with homogeneous dielectrics. Provided that the voltage applied is reasonably within the actual breakdown voltage, the risk of damage by the application of a high voltage to a homogeneous dielectric, free from mechanical damage and deterioration due to impurity or to the absorption of moisture, is extremely small. The value of a test by the Delon apparatus would therefore appear to depend, to some extent at all events, on the nature of the dielectric. The results of the tests given in the Appendix are of considerable interest, but it is to be noted that the cause of the breakdown in these tests was mechanical damage. I should be glad to learn whether any results have been obtained with high- and low-resistance faults known to be due to the presence of moisture. Insulation-resistance measurements by a skilled operator with a sensitive galvanometer will often reveal high-resistance faults, and it occurs to me that with further development of the Delon apparatus a method of test analogous to the absorption test on condensers might be evolved. In the description of the apparatus there is no mention of any device for discharging the cables after test. It is very necessary that there should be some device which would do this automatically and effectively at the conclusion of every test; the absorption on any appreciable length of cable with such high continuous-current potentials as the author mentions in the Appendix would be considerable, and the discharging device would have to be sufficiently effective to eliminate entirely risk of shock from residual charge.

Mr.  
Brooking

Mr. J. H. C. BROOKING: One may usually judge by results only, and yet get a good idea as to the technical and commercial value of new apparatus, and therefore I have been looking for results in this paper. The Delon apparatus, it may be noted, was introduced as far back as 1910, but it has been practically unheard of, although in operation in a country so near as France; and no description of it, so far as I know, has been given in any of the electrical papers, nor has anyone here apparently heard of it in practical work. There must therefore be something remarkable about the invention, or its promoters must be very modest people. With regard to the paper itself, there seem to be a number of items which are not consistent. For instance, in one place the ratio of breakdown voltages is given as 5,000 volts (A.C.) and between 15,000 and 20,000 (C.C.), a ratio of 5:15-20; whereas in another part of the paper the breakdown voltages are shown as 10:16 respectively.

Mr. Crellin

Mr. H. M. CRELLIN: With reference to the author's remark that the relation between dielectric strength and temperature is not known, I would mention that heating a cable to the temperature of boiling water does not, from test-room experience, appreciably reduce the breakdown voltage of the cable. That has already been pointed out by Mr. Beaver.\* Further, assuming that a change in the power factor of the charging current indicates a corresponding change in the breakdown pressure, we should, according to Dr. Humann's experiments† on the effect of temperature on the power factor of actual cables, get an actual increase in the breakdown pressure of a well-made cable with an increase of temperature up to 50° C. Those experiments indicated a falling power factor with a tem-

perature rising from 95° C. to 50° C.—the highest temperature to which the tanks containing the cables could be heated. This effect is quite independent of that of temperature on the capacity; the two effects want careful separating. The capacity will of course increase with the temperature, demanding a far larger charging current, but this does not necessarily involve a higher power factor. On page 609 and again on page 615, the author refers to mechanical damage during laying causing the dielectric to be crushed or cracked. Regarded purely as a check test for the purpose of discovering such a defect, the use of the Delon apparatus is well worth due consideration where alternating-current apparatus is unavailable. Let us briefly consider, however, what would happen assuming the dielectric to be partially cracked, so that it is composed partly of air and partly of impregnated paper. With continuous-current pressure the voltage-drop across the dielectric is directly proportional to the resistances of the layers. As the pressure supplied from the Delon apparatus is applied gradually to the cable, the leakage current through the dielectric will also gradually increase. The pressure across the crack will also gradually increase, being fixed by the product of the leakage current and the resistance to surface leakage of the crack (until, of course, actual breakdown across the dielectric). It may therefore happen that with continuous-current pressure the potential gradient through the dielectric may so adjust itself as not to show the presence of the crack. On the other hand, with alternating-current pressure the voltage-drop across the dielectric is fixed, not by the leakage current but by the capacities of the layers.\* Impregnated paper has a dielectric constant (or specific inductive capacity) approximately three times that of air; consequently, as the potential gradient is inversely proportional to the capacities, it will be readily seen that a comparatively low alternating pressure should easily spark across the crack and so speedily break down the fault. On page 610 it is stated that supply authorities can repeat the tests as often as desired by employing continuous current. I would warn supply authorities that some discretion is necessary, as if these repeat tests are carried out directly after taking a heavy load off the cable, the potential gradient throughout the dielectric (when testing with continuous current) may be completely reversed. Whereas a difference of temperature between the inner and outer layers of the dielectric tends to make the potential gradient through the dielectric more uniform with alternating current, a difference of temperature of but 10 degrees C. will, with continuous current, cause the outer layers to be stressed much more than the inner layers.† Regarding the figures given on page 615 showing the ratio of the continuous-current to alternating-current pressures of the Delon apparatus, it is apparently not generally realized by engineers that the ratio of secondary to primary pressures of a transformer is very much increased by the charging current of a cable, owing to the effect of the leading current on the magnetic leakage of the transformer. Every transformer has some magnetic leakage, so that this effect will be obtained on every transformer, but the amount of increase of the ratio will of course vary with the size and design of the transformer and the amount

\* *Journal I.E.E.*, vol. 53, p. 63, 1915.

† F. HUMANN: "Dielectric Losses with High-pressure Alternating Currents," *Elektronik*, vol. 58, p. 17, 1909-10.

\* A. RUSSELL: "Dielectric Strength of Insulating Materials," *Journal I.E.E.*, vol. 40, p. 6, 1908.

† A. RUSSELL: *Ibid.*, 1908.

of capacity connected to it. Testing transformers of very high voltage and comparatively low output will show the effect in more pronounced form, because the difficulty of insulating the secondary from the primary and from the core tends to the creation of a large leakage magnetic flux. The charging current further affects the voltage of the generator, the leading current strengthening the field so enormously that for the same terminal voltage the exciting current requires to be very much smaller when the generator is supplying a leading current than when it is supplying a current of nearly unity power factor. It is not very clear from the author's paper whether the figures given in the table on page 615 are due to the increase in the transformer ratio only, or if they also include the ratio of increase of generator voltage due to leading current. The point to observe is that, for the same testing pressure, different sizes of the Delon apparatus will have different ratios of continuous-current to alternating-current pressures.

Mr. J. L. LANGTON: It has occurred to me that the Delon apparatus might have an application to the testing of overhead-line insulators in situ. A few years ago the question of fatigue in porcelain insulators which had been working for some time had been investigated; there was a difference of opinion at the time as to whether the porcelain deteriorated in its chemical structure, or on account of mechanical cracks that had developed. I may say that, judging from these investigations and from my own experience in the last year, these cracks are really the cause of the so-called fatigue in porcelain. They are due to stresses set up by temperature variations produced by weather conditions, by the expansion of cement, and possibly by transit. It is not easy to find out which are the weak insulators on the system. Some attempt has been made to do this by using a "Megger," but unless the insulators are very weak this will not disclose them. It occurred to me, therefore, that such an apparatus as this would be very useful to the line engineer if the insulator, while in position, were tested with a higher voltage than can be obtained with the Megger. Of course, it could not supersede the method of testing porcelain insulators in the factory. In the routine tests\* of a factory it is absolutely essential to find out the slightest weakness in insulators, and the Delon apparatus would not disclose them. The smallest crack requires alternate stress and heating to develop into a distinct fault. I might state that the experience gained from a study of the starting of these incipient faults has led to the evolution of a better design, minimizing the stresses which have previously caused the failure of the insulation. The safety factor against puncture for overhead insulators is now at least 4. On the first page the author discusses resistance and dielectric strength. I think that when referring to the puncture strength of a dielectric (such as rubber, paper, etc.) we should speak of its "dielectric strength," but in the case of apparatus such as a cable, a line insulator, or a machine, we should use the term "electric strength." There is no relation between insulation resistance and dielectric strength. The former depends upon an inter-atomic ionization or conduction in atomic spaces, and the latter upon the atomic ionization or displacement of the atom. Air has a very high insulation resistance, but very low dielectric

strength. The dependence of its conductivity upon voltage —the saturation current—shows no connection with the dielectric strength, which, as a matter of fact, is measured by a definite stress, namely, volts per centimetre. In solid insulation of mineral origin there is no connection between the two; it has a lower insulation resistance and a higher dielectric strength than air. If there are cracks in the mineral insulation and no moisture has penetrated it, the electric strength is reduced, but the insulation resistance will still be high. With moisture present, and in the case of fibrous insulation, i.e. one of vegetable origin, or in a fluid like oil, with moisture present, there would apparently be a relation between the insulation resistance and electric strength; both may be low. As the temperature is increased, the moisture is driven out and the insulation resistance improved; but in the fibrous insulation the electric strength might become worse if the temperature were high enough. The fatigue curves (Fig. 1) for solids of mineral and vegetable origin are not quite similar, because, in the one, rupture takes place by the cracks which are aggravated by continued application, whereas in the other case rupture takes place by a charring or deterioration of the fibres, caused by the heating due to moisture, etc. The author mentions the effect of frequency on the dielectric strength. It has no effect in air, at any rate between 33 and 100  $\omega$ , and apparently not on a solid of mineral origin, such as glass or porcelain. Another point I should like to refer to is the measurement of the potential. From the sparse description in the paper I conclude that for a voltage of 100,000 or higher the instrument based on the Kelvin electrostatic voltmeter would be very clumsy, unless compressed air were used. If compressed air were used, a voltmeter of the type described in Mr. Watson's paper\* would be more suitable in size. If oil were used as the dielectric the instrument would be comparatively small. I do not see why the spherical gap† is not employed for the measurement of the high voltages. It has been adopted as a standard method for measuring high alternating pressures.

Mr. HARRY ALLCOCK: On page 609 the author refers to the considerable uneasiness experienced by the mains engineer who, by reason of the unwieldiness of alternating-current testing plant, has run the risk of putting his underground cables into commission without first subjecting them to the usual pressure test after laying. Again, under the heading "Object of Testing Cables after Laying," the author refers to the behaviour of a damaged underground cable which, although badly injured during laying, yet successfully withstands this pressure test, only to break down at an early date. He rightly ascribes this apparently treacherous behaviour to the fact that, although the damage has resulted in water entering the cable, an appreciable time must elapse before the moisture can reach the conductor and so establish a leakage path to earth. I should like to point out that the cable maker has already successfully combated this difficulty by providing what is known as a test sheath between the cable conductor and its lead sheath. This test sheath usually consists of a metal tape insulated from the lead sheath by a few layers only of hygroscopic insulating material. By making ordinary insulation-resistance tests between the test sheath and

Mr. Langton.

Mr. Allcock.

\* See *Journal I.E.E.*, vol. 49, p. 267, 1912.

\* *ibid.*, vol. 45, p. 15, 1910.

† *Ibid.*, vol. 49, p. 298, 1912.

Mr.  
Atwood.

the lead sheath it is an easy matter to detect the presence of any moisture which may have entered through a punctured lead sheath, without waiting for the complete saturation of the entire body of the dielectric at the point of damage. It is thus possible to isolate and repair a damaged cable before it breaks down. Quite apart from the invaluable assistance afforded by the test sheath during the tests which are applied immediately after a cable is laid, it will be seen that the permanent maintenance of underground cables is enormously facilitated by periodically making these simple insulation-resistance tests between the two sheaths. Towards the end of the paper the author says that the high-tension continuous-current tests he advocates are not intended to verify the dielectric qualities of the insulation, but are applied merely to show up faults which may have been produced in laying the cable. As all such faults are revealed by the above-mentioned insulation-resistance tests, I submit that the cable maker has already provided in this test sheath a means whereby the user may eliminate troubles of this character in a much simpler manner and by the use of much simpler apparatus than that described by the author.

Mr. J. W.  
Record.

Mr. J. W. RECORD: The title of the paper is rather misleading. If the word "rectified" had been used instead of "continuous" it would have given a better idea of what was to be expected. It would also have saved time if a little explanation had been given of what would happen if the capacities varied considerably. Fig. 4 is obvious, because one can make the capacities high or low as one chooses, and it seems to me that the success of the apparatus consists in keeping the two capacities forming the sides of the triangle very small so that the current required to recharge after each discharge is small. On page 614 the author mentions that a transformer of about 300-k.v.a. capacity is necessary to make the test with alternating current. Now if one uses the cables themselves as condensers instead of selecting condensers of very small capacity, one might not want far short of 300 k.v.a. From the discussion it would appear that the users of cables are quite satisfied with the articles produced by the cable makers, and the cable makers seem to think such a test is unnecessary; but should such a test prove an advantage in the future it could not be put into operation until some authority such as the Engineering Standards Committee establishes the relationship between the continuous and alternating pressures. Certain tests would be necessary before they could do this. Even, however, without carrying out tests, if the method were seen to be desirable by both cable makers and cable users it could be put into operation if the figures in the table on page 615 were laid down provisionally by some competent authority.

Mr. Nelson.

Mr. J. NELSON (*communicated*): It would seem that the paper can be best discussed under the three headings mentioned by the chairman at the Manchester meeting, viz. cable makers, cable users, and scientists. Dealing first with the cable-makers' point of view, I can only think that the author has been very unfortunate in the type of cable maker he has met, possibly a new firm who are not fully conversant with the strength of modern dielectrics, and certainly not a leading British firm. I have had a good deal of experience of several British firms and have always found that, when it comes to the actual pressure

test of the cable when laid, it has been the customer Mr. Nelson who carefully watches that the specified voltage is not exceeded. Cable makers know, and fully appreciate the large factor of safety of modern cables. I agree that the factor of safety is proportionately higher on a low-tension than on an extra-high-tension cable, but this is chiefly because it would be impossible, for purely mechanical reasons, to manufacture a commercial low-tension cable with a dielectric which is of the theoretical thickness for withstanding the electrical pressure. Nevertheless, extra-high-tension cables are sufficiently strong to withstand momentarily a pressure rise of several times the working pressure. As a proof of this there are cases in which cables are being worked at twice the working pressure for which they were built and are standing up well; moreover, I have tested cables at twice the working pressure many years after the original pressure test, and have never had a case of breakdown. I am, of course, referring to paper-insulated cables the dielectrics of which do not perish with age in any reasonable time, provided that the working temperature does not exceed, say, 150° F. The author also seems to have been unfortunate in his experience of cable-laying, since he states that cables are often subjected to strains and blows whilst being laid. I think it can be confidently stated that a cable under the control of a capable cable foreman is never strained, and no other class of man should ever be allowed to lay a cable. Mechanical damage from vehicles, etc., whilst the cable may be lying on the ground is also very rare, and when it does happen it is remedied before the cables are laid. Before leaving this subject I should like to ask the author what type of magneto instrument he uses for measuring the insulation of a cable. My experience of commercial instruments employing alternating current for measuring the insulation of circuits which contain capacity has not been exactly a success. Without going more deeply into the manufacture of cables I trust the foregoing remarks will help to remove some of the stigma cast on manufacturers. The problem of pressure-testing cables with alternating or uni-directional current at pressures over 40,000 volts does not at present greatly interest British users. Nevertheless, it is a problem which we may have to face in the near future. For the present we shall consider testing at 20,000 or 40,000 volts; and as 12 miles are referred to on page 609, it can be assumed that a trunk cable is in mind. With a cable of this magnitude it is practically certain that the work would be put out to contract, and that the pressure test would have to be carried out by the contractor. This task is not so onerous as it may seem, since although the kilovolt-amperes may number over 1,000 it must be remembered that the current will be considerably in advance of the voltage, and that by using the capacity of the cable under test against the inductance of the transformer (usually specially constructed) or suitable choking coils, the actual power taken need not be excessive. Bearing this in mind, there would be very little trouble for the user either to test the cable himself or to retest it after it was laid, if he had suitable apparatus. Assuming the cable had been originally tested after laying, it is most unlikely that the user would wish to retest it at intervals: first, because it is usually inconvenient to take a trunk cable out of commission; secondly, if a cable is working satisfactorily it is very unwise to interfere with it; and, thirdly, if

Nelson. a cable breaks down after being in commission it is nearly always due to purely local mechanical damage and can be repaired without disturbing the cable generally. On the ground of retesting trunk mains, it does not seem that capital outlay on special testing gear is warranted from the user's point of view. Dealing with medium and low-tension networks, these are usually tested when laid and it can be considered practically impossible to test them after they are laid: first, because it is unnecessary; and, secondly, it would be very inconvenient to disconnect all the instruments usually attached to a network, and also all consumers would have to be disconnected—a somewhat lengthy proceeding. I trust the foregoing will be taken as referring chiefly to supply areas of fair magnitude, and it certainly seems that from two points of view it would not be practicable for users to re-pressure-test mains once laid: first, it would not warrant the capital outlay; and, secondly, it is not practicable owing to the interruption necessarily caused to the supply. As far as paper-insulated cable itself is concerned, it could be pressure-tested at twice the working pressure for short periods almost indefinitely without harm, provided that the cable is allowed to cool to atmospheric temperature between tests. When I first heard that a paper on the testing of underground cables by means of continuous current was to be given, I looked forward with much pleasure to the reading, only to be eventually disappointed. I thought that at last we were to be given some definite information on the various methods of generating e.h.t. continuous and unidirectional current, also a description of the difficulties from a theoretical and practical standpoint which are always inherent to condensers at very high pressures, and some detailed information as to power required, weights, behaviour of different dielectrics, cables, etc. I have four main objections. First, the title of the paper is not correct, and this is far more serious than may at first seem apparent. Second, only one method of generation and testing has been described (the Delon). Third, the author has totally ignored the work of British engineers. Fourth, the paper has hardly touched the scientific side of the subject at all. Before replying to the paper seriatim, I would amplify my first objection. The author calls the method of testing "continuous" current; I can say emphatically that it is impossible to get continuous current by any such means as is described; unidirectional I agree, and only truly unidirectional if great care is taken to procure a sine wave and tap the peak, but in any case pulsating. Assuming that this is agreed, we have the three essentials to give us resonance, viz. inductance in the transformer, a spark in the rectifier (or rotating contact-maker), and the capacity of the cable or cable plus auxiliary condensers. At this stage I should like to ask the author, assuming the petrol-driven set he describes, how he manages to get a guaranteed and maintained sine wave free from all ripples. My own experience has been that the slightest departure from a sine-wave form will create serious trouble, not necessarily to the cable under test, but at least to some part of the apparatus. As an example, a voltmeter which is suitable for and has worked continuously at 50,000 volts was placed across the 1/12 tapping of a 300,000-volt transformer and, whilst recording only 15,000 volts (the transformer was only working at 180,000 volts) broke down several times, due no doubt to

high-frequency currents, at the point where the conductor enters the case through an ebonite tube  $\frac{3}{8}$  in. thick. The transformer was energized by an alternator driven by an alternating-current motor, and was working in connection with a rectifier keyed to the same shaft as the alternator. Across the rectifier was a small capacity. It is therefore possible with this type of apparatus to start oscillations in the transformer circuit and transmit them through the spark to the cable. It would seem advisable therefore to put a very high non-inductive resistance in series with the rectifier and the cable. Perhaps the author will give us his views on this point. There is a debatable point at the beginning of the third paragraph on page 608. There is no direct relation between dielectric strength and insulation in comparing different substances, but I believe that a curve could be plotted showing the relationships between dielectric strength and insulation for the same substance and at a given temperature. The same might apply for varying temperatures. On page 609 reference is given to the weight of apparatus required to test 15 km. of cable at 6,000 volts, viz. 25 tons; surely either the voltage of test is given incorrectly, or the weight given includes the engine and alternator. A transformer I have used for testing 7 miles of cable at 30,000 volts, 50  $\Omega$ , weighed 35 cwt. The curve on page 609 would be better if it were clearly stated what material it referred to, presumably it is paper insulation. It would seem reasonable to assume that with a more rigid type of insulation such as ebonite or porcelain, the breakdown pressure and the working pressure would be much closer together. I have not seen it in print before, but I believe that with experimental alternating-current testing of dielectrics at very high pressures, breakdown occurs (ignoring the direct formation of nitric acid) because of heating caused by (1) hysteresis, (2) mechanical heat due to the movement or vibration of the particles, (3) brush discharge. This would probably explain why dielectric strength decreases as frequency increases. On page 610, notice is called to the fatigue of material. The author almost seems to be under the impression that the object of pressure-testing a cable is to get as near to the breakdown point as possible without puncturing the insulation. Fatigue does take place, but in taking the example given (viz. if a cable breaks down at O A' (Fig. 1) in 10 minutes, it will break down in a shorter time at the second application of the same pressure) it would be interesting to know whether the cable was immediately retested or whether it was allowed to fall to atmospheric temperature before retest. This is an important point, because oil-impregnated paper-insulated cables have a well-known facility of recovering themselves. This fact alone emphatically disproves that manufacturers object to cables being retested at more than the working pressure. Dealing briefly with surges, the pressure rise has to be enormous momentarily to puncture a cable, as no time is assumed to allow the cable to heat up. This being so, it is reasonable to assume that when a surge does occur of sufficient magnitude to puncture, damage is usually local and does not necessarily fatigue the insulation of the whole cable. Coming to the advantages of continuous-current testing, the chief of these, as the author states, is the small charging current taken, the machine only having to supply the current

\* Misprint, since corrected.

Mr. Nelson.

due to the leakage through the dielectric and the usual brush discharge at the terminals and cable ends. There seems, however, to be one disadvantage, viz. once the cable is charged up, the dielectric is under unidirectional stress, and I do not think this subjects the insulation to anything like the stress that alternating current would, owing to there being practically no heating produced. This is not such a drawback as it may seem, as the properties of the materials used in cable insulation are fairly well known, but it would be a drawback in determining figures in connection with a new form of insulation. What continuous current will do equally as well as alternating is that it will find, by puncturing, the weak spots in the cable or joints; but, as the author states, the proportion between alternating and continuous current must be something more than  $\sqrt{2}$  to 1, depending, as I have said before, on the class of dielectric. The description of the Delon apparatus leaves much to be desired. I have already asked the author several questions about the method of ensuring that resonance does not take place. There are, however, several other points which are not clear. First, on page 610 condensers are shown, and I understand these have to be used whenever the cable has not sufficient capacity to remain charged during the whole cycle. What type of condensers are used? Mr. Watson has already told us\* some of his troubles, and it would be interesting to know of condensers which can be carted about and which will work at 200,000 volts. Secondly, Fig. 3 shows one side only of the transformer connected through the rectifier to the capacity. Would there be any advantage if both sides were connected through revolving discs, so that when one side of the condenser was in contact with the positive peak the other would be in contact with the negative peak? Thirdly, the author states on page 612 that the capacity of the cable may be so great that it takes several periods of contact to charge it up. This being so, are any curves available showing the time taken to bring, say, 10 miles of 0.125-sq. in. single-conductor 100,000-volt continuous-current cable from zero to 150,000 volts? I am inclined to think the time taken to charge to 150,000 volts would be greater proportionately than the time to charge to 80,000 volts given in the Appendix. Also, has any trouble been experienced due to the sudden overload thrown on the transformer at every revolution of the rectifier until the cable is charged? The voltmeter described is well known, and a similar instrument made by a British firm has been used by myself for measuring voltages up to 300,000. Dealing with the potential that should be adopted, my foregoing remarks show that my own experience has been in agreement with that of M. Laporte and that the ratio is much more than  $\sqrt{2}$  to 1. It is a pity we are only given particulars of a breakdown on 20 yards of cable. I do not think there is any doubt that, given a long length of cable, the puncture would be sufficiently charred to enable an ordinary loop test to be made. Assuming 1 mile of 10,000-volt single-conductor cable having a capacity of 0.2 mfd., the theoretical number of watts which would pass through the puncture, assuming it took 1 second to pass, would be 10, and as 1/50 second would be ample time for the discharge, it would increase the number of watts to 500. Taking a cable 7 miles long and having a total capacity of 1.4 mfd. charged to 100,000 volts, and assuming the dis-

charge took place in 1/50 second, the power dissipated would be 350 kw. This would be equivalent to 510 ft.-lb. and would be surely sufficient to cause a fault which could be easily located. One has also to bear in mind that the discharge would probably be oscillatory and that diminishing intermittent currents would pass several times after the main discharge. I have had experience which confirms this point. The author might also have given us some information about the use of valves for obtaining unidirectional current. In conclusion, I should like to support Professor Marchant's remarks with regard to the work done by Mr. Watson on continuous-current testing. I am hoping, in the near future, to hear that Mr. Watson is reading a paper describing his truly continuous-current apparatus.

Mr. O. L. RECORD (*in reply*): I quite agree with Mr. Beaver that the effects obtained with continuous and with alternating current may be quite different, and it is only by experiment that the ratio of the continuous to the alternating potential which will have the same breakdown effect can be determined. Generally speaking, under check-test conditions the variations in the insulation resistance of a particular cable are a very fair guide as to the dielectric strength, but it is quite conceivable that conditions might arise which would decrease the dielectric strength without decreasing the insulation resistance. For instance, in course of time the cable might be heavily overloaded and thereby kept at an abnormally high temperature, resulting in the drying up of the impregnating material, and whilst the insulation-resistance test might show the original or even a higher value, the dielectric strength might be reduced. Mr. Langton's remarks on this point are instructive. The cable least likely to break down is not always the one which shows the highest insulation resistance, as Mr. Ratcliff points out. With regard to the transformer used with the Delon apparatus, it is quite true that it has to give approximately the same voltage as the transformer for the alternating-current test, and that the sole advantage as regards size and weight is that it has to be designed for only a small current, but there is all the difference between a 3-kw. 30,000- or 40,000-volt transformer, which is all that is required with the Delon apparatus, and a 500-k.v.a. transformer of the same voltage which may be necessary for the alternating-current test. I quite agree with what Mr. Beaver says regarding the question of fatigue if applied to cables up to 10,000 or 11,000 volts, but with 40,000, 50,000, or 60,000-volt cables it is not practicable to have anything like the same margin of safety, and it is then found that precautions have to be taken which were unnecessary with the lower voltages. As Mr. Welbourn pointed out in the discussion before the Institution (page 616) faults due to moisture are more readily dealt with by continuous than by alternating current, and it has been found that the Delon apparatus will deal quite satisfactorily with faults of this kind.

In reply to Professor Marchant, the experiments which have been carried out appear to show that the ratio of the continuous to the alternating breakdown pressure is constant in the case of paper- and rubber-insulated cables, and that the ratio is practically the same in these two cases. Nevertheless, it does not follow that the ratio would be the same in the case of other materials. I agree that heating due to dielectric hysteresis would appear to be the cause of fatigue. Mr. Rayner's experiments seem to prove this,

Mr. Nelson.

Mr. O. L. Record.

\* Journal I.E.E., vol. 45, p. 5, 1910.

O. L.  
ord.

and they also show that under certain conditions this fatigue may be permanent.

Mr. Ratcliff does not consider that a continuous-current test meets the requirements of a test under working conditions on alternating-current cables. I agree and I would not advocate replacing the usual factory test, which can include any refinements such as those suggested, by continuous current. As, however, the object of the test after laying is merely to ensure that the cable has not been injured in this process and that the joints are good, there does not appear to be any reason why continuous current should not be used; it is merely a question of those concerned agreeing upon the value of the voltage to be employed for the test. I am very glad to note that Mr. Ratcliff endorses the statement that there is no definite relationship between dielectric strength and insulation resistance. By ordinary temperatures I mean any temperature that will not alter the constituency of the insulating material. The statement that the dielectric losses increase appreciably with increase of temperature, is not strictly correct. It appears to be so, owing to the fact that the dielectric losses are themselves the chief cause of the temperature rise, but if the temperature is varied independently, it will be found to have practically no effect on the breakdown voltage. I agree that Figs. 1 and 2 show the importance of testing with alternating current to verify the dielectric qualities of the insulation, and for this purpose a continuous-current pressure cannot perhaps be regarded as equivalent to the alternating one, but this is not the object of testing after laying, as already pointed out, and for this latter test it has been shown that an equivalent value can be found and that a continuous-current pressure is perfectly satisfactory for such tests. A great deal of experimental work has, however, still to be done to determine the equivalent value for different materials under different conditions. The work which has been carried out so far is merely a beginning, but enough has been done to show the possibilities of the method and I hope to induce others to take up the subject.

In reply to Mr. Fernie, I would point out that if the figures given in Table E of Mr. Rayner's paper<sup>2</sup> already referred to are plotted, similar curves to Fig. 1 are obtained. I do not consider the figures he puts forward necessarily depart from the law of this curve. It is unfortunate that the time required for 91.5 kilovolts to cause breakdown is not given; for the curve shows that if the potential is very slightly less than the limiting value O A which will just cause breakdown, it can be applied indefinitely, whilst the period during which the limiting value can be applied before causing breakdown is only about 10 to 15 minutes. Similarly in the case of change of frequency the time is the determining factor. If a certain voltage at a certain frequency will produce breakdown in a certain time, the same voltage at double the frequency should theoretically produce breakdown in half the time, since the hysteresis loss will be doubled, but this does not mean that half the voltage at double the frequency will cause breakdown in the original time. As a matter of fact, it will be seen from Fig. 1 that the reduction in voltage at the flattest part of the curve corresponding to half the time will be inappreciable. It will gradually increase, however, with the steepness of the curve, but at the steepest part of the curve the breakdown

<sup>2</sup> *Journal I.E.E.*, vol. 49, p. 10, 1912.

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time is so short that the reduction in time due to increase in the frequency is not appreciable; consequently when the reduction in voltage becomes of any importance it is impossible to determine it, as the breakdown time is practically instantaneous. Mr. Fernie's figure of 5 per cent would therefore not appear to depart from the law of the curve. I do not agree with him that nearly all the statements about dielectrics should be accepted as true rather for a specimen than for a substance. I am of the opinion that they are as a rule true for a substance, but that they may only appear to apply to a specimen owing to the great difficulty in making exact and consistent measurements. The question of the opposition of cable makers to the repetition of high-tension alternating-current tests, I have dealt with in my reply to the discussion before the Institution (page 622). As pointed out in the paper, it is unnecessary to use condensers in the case of multi-core cables. Nevertheless, the makers of the Delon apparatus have designed special condensers for the purpose which have proved perfectly satisfactory.

Professor Field's mechanical analogy is interesting but must not be carried too far. As Professor Marchant points out, the fatigue of insulating materials is not due to dielectric strain but to heating produced by dielectric hysteresis, and as this heating does not occur with a continuous voltage, there is no fatigue, so that no matter how often the voltage is applied, removed, and re-applied, it will not cause breakdown if it is below the steady breakdown value. I am afraid I cannot say definitely whether the ratio of continuous to alternating breakdown pressure would be the same for a failure over a creepage surface as for direct puncture. The tests described in the first column on page 614, however, would appear to show that it is. As mentioned in reply to Mr. Ratcliff, there is still a great deal of experimental work to be done in connection with this ratio.

The various points mentioned by Mr. Symons have already been raised by other speakers and replied to.

In reply to Mr. Brooking, an attempt was made to introduce the Delon apparatus into this country in the early part of 1912, but when it was realized that it entailed altering not only the standard specifications but also the Board of Trade regulations, the attempt was abandoned. It must also be remembered that owing to the fact that there are even now only a few systems in this country working at more than 11,000 volts, there has been but little difficulty in making alternating-current tests and little to be gained by the use of the Delon apparatus. Meantime it has been extensively used in France, and from recent information received from the makers there are now few cable systems of any importance in that country on which it is not used. Whilst Mr. Brooking makes a general statement as to a number of items in the paper being inconsistent, he only specifically mentions one instance. In that case the apparent inconsistency is due to his comparing together two entirely different ratios. For whilst the first set of figures he quotes are actual breakdown voltages, the second set, which are taken from the table on page 615, are not; what they give is the ratio of the continuous-current pressure supplied by the Delon apparatus to the high-tension alternating pressure applied to it.

Mr. Crellin's deduction that the breakdown pressure of a

Mr. O. L.  
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well-made cable should increase with temperature up to 50° C., would appear theoretically to be the case; for Höchstädtler found that for high-tension cables the dielectric loss rapidly diminished between temperatures of 10° C. and 40° C., after which it increased fairly rapidly.\* Consequently, as the cause of breakdown of high-tension cables would appear to be due to heating produced by dielectric hysteresis, any factor which reduces the dielectric loss should increase the time required for breakdown. Conversely, it should require a higher voltage to cause breakdown in a given period, but for the reasons pointed out in reply to Mr. Fernie in connection with the question of the effect of the change of frequency, the increase of voltage corresponding to a reduction in time is quite small except in the case of practically instantaneous breakdown, and as the reduction in time due to the decreased dielectric loss would be small, the increase in breakdown voltage would be negligible. Mr. Crellin's argument as to the relative effect of alternating and continuous-current potentials in regard to a crack would appear to be in brief that, whereas with alternating current the greater part of the potential gradient would be across the crack and so cause sparking and a speedy breakdown of the fault, with continuous current the potential gradient might adjust itself as if no crack existed; but assuming this to be so, as the resistance of the crack would be higher and the dielectric strength lower than that of the insulating material, the potential across the crack, if sparking is not to occur, would have to be much less than across the same thickness of sound material. Consequently, the potential across the rest of the dielectric would be increased and breakdown would occur. The point Mr. Crellin raises as to the increasing transformer ratio has no influence on the results given in the table on page 615, as the pressure is that actually measured on the high-tension side of the transformer. The increasing ratio appears to be due to the relatively smaller influence of the loss at the spark contacts at the higher potentials. The potential of the primary side of the transformer can always be adjusted by means of the rheostat provided, so that the exact potential required on the continuous-current side of the apparatus is obtained.

In reply to Mr. Langton it has not been found possible with the Delon apparatus to charge up an overhead line; the charging current is dissipated as fast as it is supplied. I am very glad that Mr. Langton confirms there is no relation between insulation resistance and dielectric strength. His remarks in this connection are extremely interesting. I have already dealt in my reply to Mr. Fernie with the question of the effect of change of frequency. I am sorry I was not able to include in the paper an illustration of the Abraham-Villard electrostatic voltmeter, but, as I have already remarked, the illustrations I have were unsuitable for reproduction. An electrostatic voltmeter for 100,000 volts on the Kelvin principle would certainly be very clumsy unless compressed air or oil were used to prevent sparking over.

Mr. Allcock gives further particulars of Mr. Beaver's test sheath which has already been referred to. I can only repeat that if this method of testing were adopted

\* The reason of this would appear to be due to the relative variation of the properties of the material, namely, resistance and capacity, with temperature, as is clearly set out by Mr. Kayne in his paper already referred to.

there would, of course, be no need for the ordinary Mr. O. L. alternating-current testing apparatus at present used, Record.  
and consequently for the Delon apparatus.

In reply to Mr. J. W. Record, if the current given by the Delon apparatus should not be described as continuous, no more should that given by an ordinary continuous-current generator; in both cases the current is rectified, whilst the ripples are less accentuated in the former than in the latter case. The question of capacity has really very little influence, for although an increase in the capacity will increase the time required to charge up the cable to the full potential, yet under the worst conditions occurring in practice and with the output of the transformer limited to 3 kw., the time is so short—only a few minutes—as to be of little importance. I agree that a sine qua non for the adoption of the Delon apparatus is that the cable makers, cable users, and the authorities concerned should agree upon the value of the continuous-current pressure to be employed.

In reply to Mr. Nelson, I have already explained my remarks with regard to the cable makers in my reply to the discussion before the Institution (page 622). I have also made clear that the paper refers to cables for voltages higher than those ordinarily met with in this country, as this point did not appear to be understood. I quite agree with what Mr. Nelson says regarding extra-high-tension cables, as I presume he refers to cables for voltages from 3,000 to 11,000, that is below the range I had in view. For measuring the insulation of a cable, I consider the "Megger" to be one of the best instruments. Mr. Nelson suggests keeping down the output of the testing transformer by using a choking coil to neutralize partially the effect of the capacity of the cable. This method of working as employed by the India Rubber, Gutta Percha, and Telegraph Works Company for testing the cores of submarine cables was described some years ago by Mr. S. A. Russell in the Electrical Engineering Supplement to the *Engineer* of 12 December, 1902. I understand, however, that the method was very soon abandoned as it was found impossible to avoid dangerous resonance effects. Mr. Nelson then sets out to show that there is no need for and no likelihood of cables being retested after once being laid; but cables do have to be retested occasionally, for instance after a breakdown, and the original test after laying has to be taken care of, so that it would still appear to be worth while trying to develop improved methods of testing. Whether a paper cable can be tested at double working pressure for short periods almost indefinitely without harm, depends upon the factor of safety, which in turn depends upon the working voltage and on what is meant by short periods. I am sorry Mr. Nelson has been disappointed with the paper. I trust, however, that he has found some slight consolation in the excellent discussion which has resulted. Mr. Nelson objects to the word "continuous" in the title of the paper. Is the current given by the ordinary continuous-current generator truly continuous? Of course it is not, though we speak of it as such. It is made up of a series of uni-directional waves following rapidly one after the other. In a similar manner the current given by the Delon apparatus consists of a number of uni-directional impulses following rapidly upon one another; no special precautions have been taken to ensure a sine wave, and yet

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ord.

no trouble has been experienced due to resonance. I wonder what type of rectifier was used by Mr. Nelson. The question of dielectric strength and insulation resistance has been dealt with very fully by Mr. Langton and I do not think I can do better than refer to his remarks on page 629. With regard to the weight of apparatus to test 15 km. of cable, the voltage given in the footnote on page 2 of the advance copies of the paper was obviously wrong; it should of course have been 60,000 volts. I pointed this out at the meeting, but evidently Mr. Nelson was not present. Fig. 1 is given as a typical voltage-time curve and is true of most insulating materials. Fig. 3 is merely a diagrammatic sketch to show the action which takes place; as stated in the paper, condensers are seldom used. I am afraid I do not know of any portable condensers to work on 200,000

volts. The limit of voltage of the portable Delon apparatus is 150,000 volts, which means that the condensers would be charged to 75,000 volts only. No advantage would be gained by having a revolving disc on each side of the transformer; a double disc is used for voltages beyond 100,000, but this is merely done to keep down the diameter without running any risk of sparking over. I take it that the curve Mr. Nelson would like is one showing the growth of the voltage with time. I regret I have no curves of this kind. Naturally the higher the voltage the longer the time required to charge up the cable, other things being equal, but under the worst conditions the time is quite reasonable, a matter of a few minutes. The other points raised have already been dealt with in reply to other speakers.

Mr. O. L.  
Record.

## YORKSHIRE LOCAL SECTION, 9 FEBRUARY, 1916.

Wright,

Mr. H. H. WRIGHT: On page 608 the author says that at all ordinary temperatures the voltage which will produce a breakdown does not vary much. I shall be glad if the author will explain what are the limits of the ordinary temperatures to which he refers. Does he mean those temperatures which are likely to arise in a buried cable due to dielectric losses? Under these conditions the breakdown voltage is not independent of the temperature and it occurs at a much lower figure as the temperature increases. If the rate of generation of heat in the dielectric is greater than the rate of dissipation, the temperature will gradually rise until a breakdown occurs. In regard to the Engineering Standards Committee's specification for testing cables, which prescribes twice the normal voltage for 30 minutes, I find that the Standardization Rules of the American Institute of Electrical Engineers also specify twice the normal voltage, but only for one minute and at the normal frequency of the system. This applies to all apparatus for which the test pressure does not exceed 10 kilovolts, except apparatus of a very large static capacity or a large cable system. It seems to me that a 1-minute test is too short, since the dielectric has not time to heat up, and I think the temperature effect is therefore lost. I should also like to ask the author whether he has found any difference in his tests due to polarity effect on reversing the charge from positive to negative. The figures for equivalent breakdown pressure given in the Appendix for continuous current as against alternating current are certainly interesting, and they prove that alternating current has a much greater penetrative effect than continuous current. I have seen no satisfactory explanation of this fact, unless it be due to the fatiguing action of the alternating current, in other words to chemical action in the dielectric which is not produced by the continuous current. I assume that the tests given in that table were taken with a frequency of 50 cycles and at ordinary temperatures, although that is not stated to be the case. On page 611 the author mentions that the charging up of a certain cable took less than one minute. As the question of a smooth increase of voltage is of great importance in testing cables I should like to ask him whether he has any records or curves showing whether that charging takes place quite smoothly. He also does not state what hap-

pens after the test, when the voltage is reduced. Is there also a smooth reduction of the voltage as soon as the current is cut off from the transformer?

Mr. Wright.

Mr. R. H. CAMPION: What impressed me most in reading the paper was the difficulty that all engineers responsible for extra-high-tension mains must have in getting the proper tests after the mains are laid when the testing pressure required is above 20,000 volts. Up to that voltage there does not seem to be much difficulty in applying the required pressure, but after the mains are laid it is ever so much more difficult, particularly on a long network, and I suggest that pressure tests are rarely applied to mains after they have been laid. Reliance is placed on surges and similar effects to take the place of such a pressure test. The author considers that in most cases single-conductor cables are constructed to transmit only low-pressure continuous current. We have recently seen that single-conductor cables will probably be used mostly for transmitting very high pressures where the route crosses a railway and in other places where overhead wires are prohibited; this apparatus will therefore have to deal with such cases as well. My experience is that one should rely on insulation testing up to a certain point and then wait for some act of God, such as for the mains to be struck by lightning, which will bring out the small faults that may have been in existence for years without causing the cable to break down.

Mr.  
Campion.

Mr. C. J. JEWELL: With the apparatus described it seems possible to carry out the high-pressure tests on long lengths of cable without the trouble and inconvenience often experienced with the double-pressure alternating-current test. As far, however, as results go there does not seem to be any very clear indication as to what continuous-current pressure would be necessary to have the same test effect as the usual alternating-current test of twice the working pressure. I should like to ask the author whether in the various tests he has found any difference between the results with a cable having a low insulation resistance and one of similar length with a high insulation resistance. It is common knowledge that the different compounds or oils used in the various types of paper cables are very liable to show large variations in the insulation-resistance test. I wonder whether this has any bearing on the ratios

Mr. Jewell.

Mr. Jewell. given. I should imagine that this method of testing would be very useful, particularly when one has had a bad breakdown on a long length of feeder and one wishes to apply a pressure test after the repair without at the same time applying the pressure with a considerable amount of power behind it, as might be the case if one were to use the ordinary alternating-current apparatus. Another useful feature of the apparatus is that it is possible gradually to break down a high-resistance fault, which is a somewhat risky proceeding under ordinary conditions.

Mr. Chaytor. Mr. A. R. CHAYTOR: I was always under the impression that the best method of testing anything was to put it into a condition which would be as nearly like the actual working condition as possible, making the duty more severe than the working load to an amount depending on the safety factor desired. Now, in my opinion, the stresses set up by the pressure due to an alternating current can be likened to those resulting from a bombardment, as compared with a steady thrust in the case of continuous pressure, and for this reason I would prefer to have an alternating-current test on alternating-current apparatus; and I would consider it to be only a poor alternative to use a continuous pressure, even if an allowance, as proposed in the paper, were made. I consider a satisfactory test for an e.h.t. alternating-current cable to be one in which the full working voltage is applied and then the pressure increased to that at which it has been decided to conduct the test, i.e. in the case of a 10,000-volt cable to apply at first 10,000 volts, and then to increase the pressure gradually to 20,000 volts. I might say that I do not consider any useful purpose is served by prolonging the test to one hour, as is asked for in some cases, 10 minutes in my opinion being quite sufficient. I should like to know whether the author could test a length of e.h.t. transmission line in which overhead line and underground cable are interspersed (as is frequently met with in this country) in which the overhead line has a low insulation resistance but a high breakdown point. Referring to Fig. 6, would there not be some danger of a sudden increase to double pressure in core No. 3 in the event of the other core breaking down to earth, or vice versa, due to the condenser effect? I am particularly interested in the remarks on the burning out of faults, and I should like to know whether the author could with this apparatus consistently burn out faults to earth due to moisture, for I see no means provided whereby we can discriminate which polarity we should put on the bad core to start burning out the fault. It frequently happens that if one starts to burn out a fault of this character with the positive pole on the faulty core one will temporarily clear the fault by driving the moisture back. Regarding the examples of practical tests given on page 614, I should like to point out that the pressure at which the tests were made, viz. 30,000 volts (continuous), is only approximately near to the breakdown effect of that due to 10,000 volts (alternating), which is the actual working voltage. The cable could therefore have been tested quite as effectually without any transformer by simply switching it on to the system it was to work on. In any case, a much smaller transformer than one of 300 k.v.a. would have been large enough for testing this cable at 10,000 volts alternating, which is equivalent to 30,000 volts continuous.

Mr. Hartnell. Mr. W. HARTNELL: From this paper it appears that the

insulation of electric cables may be permanently injured by prolonged exposure to alternating voltages which approach the breakdown limits; whereas continuous voltages produce no such injuries. The conclusion follows that after a cable has been laid, any high-voltage test should be made with continuous current. An important question arises. Should electrical engineers make any very high-voltage tests on an expensive cable in situ? Might not the long-established practice of mechanical engineers be followed with advantage, viz. never test materials in a finished structure. For example, suppose an important bridge is to be built. All tests of material are made before the design is complete. The bridge is then built under vigilant inspection. After completion no reckless tests are made to prove the strength of the material or show the factor of safety, but only such as are deemed advisable for determining mechanical points, such as good workmanship, deflection, etc. Is not the most rational course in regard to costly cables, expensively placed underground, to make convincing tests of the materials or samples before the manufacture of the cable is commenced? Inspect and test during construction, but after the cable has satisfactorily left the makers' works and is carefully placed underground, test it at no higher voltages than requisite to prove that all is in good working order.

Mr. W. E. BURNAND (communicated): Regarding the statement on page 609, that the breakdown voltage for an alternating pressure is a function of the time, I think this might be more correctly stated as being a function of the temperature at the point of breakdown. I thought it was established by Mr. E. H. Rayner that the so-called fatigue of insulation material is a matter of alteration due to high temperature, rather than any electrical molecular alteration of the material; this being so, it clears up many doubtful features. For instance, in Fig. 1 we can hardly say there is any fatigue however long the pressure is kept on, at a pressure of OA'. Also at the pressure OA apparently the voltage could be kept on indefinitely without any so-called fatigue. At the pressure corresponding to OA', where the breakdown occurs with time OB' it seems to me that this is not a function of the insulation alone, but is very largely dependent on the cooling of the electrodes: for instance, with small electrodes or a small cable with a small heat capacity, the time OB' would be very much shorter than if the electrodes were large and had a big heat capacity, under which conditions the temperature of the insulation between the electrodes would rise only slowly. The time would then be very much longer, and if the electrodes were large enough or so arranged as to keep the temperature down by conducting the heat rapidly away from the insulation, it is quite conceivable that the whole curve would have to be raised till the voltage OA' corresponded to the horizontal part of the curve marked OA in Fig. 1. The first paragraph on page 610 also appears to me to require modification, as this fatigue can only be considered permanent if the test pressure has been such as to injure the insulating material, this injury apparently consisting, in the light of Mr. Rayner's researches, of incipient burning of the material. The ordinary test pressures, however, do not get anywhere near this stage, but correspond more to the voltage OA' in Fig. 1, so that there should be no

more danger of injuring the apparatus with a suitable alternating pressure than there is with a continuous pressure. It seems to me, therefore, that the advantage of the test with continuous current is its ease of application when testing apparatus having considerable capacity, this applying especially to cables, and, as the author states, to test the long cable with a high alternating voltage requires an apparatus altogether too cumbersome for practical use. I do not think a continuous-current test can altogether displace the alternating-current test, as it is a test of dielectric strength, but not of dielectric hysteresis, which is a very necessary test for apparatus for use with alternating current. At the same time I quite agree that if an alternating-current test be made at the factory, a continuous-current test, as suggested, after laying the cable is quite sufficient, as this definitely locates any weakness of the insulation if such has occurred in the interval, and it would be unreasonable to expect any alteration in hysteresis loss in the course of a few days or even a few weeks under normal conditions. I do not think we can say yet that this dielectric hysteresis of a cable does not alter in a considerable time, and until this is settled it would seem rather doubtful if the continuous-current test will be sufficient throughout the life of the cable. The half ton of apparatus mentioned on page 611 looks rather heavy for a portable apparatus that has to deliver only a few hundred volt-amperes, and it would appear possible to reduce this considerably. Also it would appear not impossible that an electrical influence machine could be developed for this work which would be still more portable. Regarding the condensers mentioned, I should be glad if the author would say what type of condenser is used for 100,000 volts and over. Regarding the paragraph on page 614 headed "Indefinite Repetition of Tests," I do not consider that the continuous-current test has any advantage over the alternating-current test as regards repetition, provided the latter does not reach a value that will injure the insulation. It simply means that this is to be a considerably lower value than the continuous-current test, and whilst this is certainly lower than the latter, it is more complete, in being a test of hysteresis as well as of dielectric strength. Regarding the nature of the charge given to the cable, I agree that this is practically a steady continuous pressure on the apparatus tested, but on the beginning of the charge when the pressure on the cable or apparatus under test is very small, and that at the discharging point fairly high, this gives a particularly vicious kick on the testing transformer, which is very likely to break down the insulation of the end turns, unless these are specially insulated to deal with this kick, and I believe that considerable trouble has been experienced due to this. Where there is any doubt, therefore, it would be advisable to have a choking coil close to the transformer terminals, which would cushion this discharge to some extent; and a condenser at the transformer side of the choker would still further cushion this, but at the same time these—and especially the condenser—are not things that would be too lightly installed for these very high test-pressures, so that probably for regular work the simplest and cheapest plan is to make the transformer suitable for taking these shocks, and the auxiliary apparatus would only be used for particularly severe work beyond what the transformer was designed for. Regarding the

table on page 615, in spite of the ratio remaining somewhere about 2·5 as shown, I do not think this ratio is capable of anything approaching universal application, as it is a ratio that is profoundly affected by the thermal characteristic of the insulation and electrodes, and also by the dielectric hysteresis of the insulation.

Mr. O. L. RECORD (*in reply*): Replying to Mr. Wright, by ordinary temperatures I mean any temperature that is not of such a value as to alter the constituency of the insulating material. It must of course be understood that the temperature variation is produced by means external to the cable itself. If the temperature rise is the result of the hysteresis loss, the breakdown voltage will of course be reduced. I agree with Mr. Wright that a 1-minute pressure test is too short, as a test of this duration does not take any account of the temperature rise due to dielectric losses. As pointed out in connection with Fig. 1, the critical time would appear to be about 15 minutes; consequently, the duration of a pressure test should not be less than this. Up to the present no experiments have been made to find the effect of change of polarity, and I am not therefore in a position to give any information on this point. The fact that the ratio of the continuous to the alternating-current pressure which will have some breakdown effect is greater than  $\sqrt{2}$  to 1, would appear to be due to the dielectric losses and consequent heating produced by the alternating current; with continuous current this heating does not occur. I hardly think it is a question of chemical action, though it is quite possible that just before breakdown occurs the temperature may reach such a value as to alter the chemical composition of the material. The table on page 615 does not give the ratio between continuous and alternating-current breakdown voltages but the ratio of the continuous-current voltage given out by the Delon apparatus to the high-tension alternating-current voltage applied to it; consequently, the question of frequency and temperature does not arise. I am sorry I have no curves to show the growth of the potential with time. At the end of the test great care must be exercised in discharging the cable if breakdown is not to occur. The simplest way to effect this is to continue to run the contact-maker whilst the voltage is reduced, thus allowing the cable gradually to discharge.

I am pleased to note Mr. Campion's remarks re the difficulty of making pressure tests on long mains when the voltage is above 20,000, and whilst I cannot agree that pressure tests are rarely applied to mains after they have been laid, still cases do arise (and they are likely to be more frequent in the future as higher pressures become more common) where it is not possible to make such tests with alternating current on account of the size and weight of the apparatus required. It is quite possible that higher pressures will be attained in the future with single-core than with multi-core cables; in such cases the full pressure of the Delon apparatus, namely, 100,000 or 150,000 volts, can always be obtained by the use of the auxiliary condensers.

In reply to Mr. Jewell, the experiments of Dr. Lichtenstein described in the Appendix show a mean ratio between the continuous-current and alternating-current breakdown pressures of 2·6 to 1 for paper-insulated cables and approximately the same ratio for rubber-insu-

Mr.  
Burnand.

Mr. O. L.  
Record.

Mr. O. L.  
Record.

lated cables; approximately the same figures have been found by other investigators. Consequently, a continuous-current pressure test should be made at about 5·2 times the working voltage. The insulation resistance of a cable does not appear to affect the ratio, though I have not made any special investigation into this point.

I quite agree with Mr. Chaytor that the effects produced by continuous and by alternating current may be quite different and that alternating-current apparatus should be tested with alternating current; but this alternating-current test is always made on cables in the factory, and as the test after laying is merely to ensure that no damage has occurred and that the joints are good, there does not appear to be any sound reason why continuous current should not be used for the purpose. I quite agree that no useful purpose is attained by prolonging the test for one hour. I think the time might very well be fixed at 15 minutes. It is not possible with the Delon apparatus to test extra-high-tension cables connected to an overhead line, as it is found impossible with the apparatus to charge up such a line, the insulation resistance being too low. With regard to the effect on conductor 3 in Fig. 6 if one of the other conductors should break down, in Fig. 6A conductor 3 is the intermediate point, the potential between it and between the other conductors and the lead being only half the full test pressure. The breakdown of conductor 1 or 2 would be equivalent to connecting *a* to *b*, the result being that the potential between 3 and the lead

would drop to zero, alternate charges being of opposite sign. In Fig. 6B the lead is the intermediate point and is at earth potential, whilst the full test potential is between conductors 3 and 1 or 2, and half the full test potential between each of the conductors and the lead. Consequently, a breakdown of conductor 1 or 2 would not affect the potential of conductor 3. Mr. Chaytor raises a very interesting point in connection with the burning out of faults to earth due to moisture. The difficulty pointed out has not been experienced, the apparatus dealing quite successfully with faults of this kind. It is quite true that the transformer used with the Delon apparatus has to give practically the same potential as the transformer for the alternating-current test, but whereas in the latter case any capacity up to 500 k.v.a. might be necessary, a 3-kw. transformer is all that is required for the continuous-current test.

I think there is a good deal to be said in favour of Mr. Hartnell's suggestion in connection with cable tests. The fact that static apparatus is being used in some cases for the tests after laying, would seem to indicate that there are other engineers of much the same opinion.

In reply to Mr. Burnand, I have already dealt with the question of fatigue. I agree that where the length and capacity of the cable to be tested is such as only to require a few hundred watts, the weight of the apparatus can be considerably reduced. The output has, however, been fixed at 3 kw. so as to be able to deal with any conditions likely to arise in practice.

Mr. O.  
Record.

## SERVICE BRANCHES FROM EXTRA-HIGH-TENSION CIRCUITS.

By D. M. MACLEOD, Member.

*(Paper first received 3 December, 1915, and in final form 24 March, 1916; read before the SCOTTISH LOCAL SECTION 11 April, 1916.)*

With the rapid growth and development of power supply from central generating stations generating and delivering alternating current, the problem of an efficient and economical mains lay-out has become of paramount importance, as therein largely lies the supply authority's ability to give power and lighting supplies, small and large, on terms attractive to the consumer and reasonably remunerative to themselves.

In the case of, say, a modern power company operating by virtue of its Parliamentary powers over an extensive area of comparatively widely-scattered industrial communities, it is quite conceivable that as development progresses the outlay in mains and services per kilowatt of demand on the generating station will exceed the cost per kilowatt of generating plant and power-house buildings to give such demand. This being the case, every method and device must be inaugurated and tried to reduce to a minimum the outlay involved in feeder and network extensions, compatible with reliability of supply.

In the providing and maintenance of such alternating-current power supplies, the ring-main system of distribution possesses undoubted advantages, one of the most important being that supply can be maintained to all consumers even though a fault should occur at one point on the ring circuits. It is not surprising therefore to find the ring-main system extensively used for public electrical distribution networks, the route of such ring circuits being generally laid out to follow a certain line of actual or prospective development.

To achieve the best results from this method of distribution it is essential that some system of balanced protective gear should be installed, as it is exceedingly difficult, if not impracticable, so to arrange a series of overload and reverse-power "trips" as to give the necessary discriminative action when isolating a section on which a fault has developed. Attempts have frequently been made to grade a system of overload protective devices so that any cable failure can be localized as much as possible, but generally these attempts have either failed completely or the results obtained therefrom have been of so uncertain a nature as to lead to their abandonment. Such a result is what one might expect in all cases except, say, that of a feeder energized and fed from only one end.

When a supply is required for a large power consumer, there is seldom any question as to its being obtained from or incorporated with the nearest available ring main, even should the consumer's works be situated some distance therefrom, as the importance of the supply on the commercial as well as on the engineering side is such as to justify the capital expenditure involved in looping in the ring-main circuit and providing the necessary sub-station and balanced protective equipment.

In some cases, however, and these are by no means

uncommon, a comparatively small supply for an isolated works may be all that is required, or a new works may be starting up, the ultimate development of which is a matter of uncertainty; or again the supply may be required simply to augment the output from a private plant or as a week-end and stand-by supply to such plant. In the cases enumerated, both the financial and the engineering aspects of the problem require very careful consideration, more especially where the works to be supplied are situated at some little distance from the route of the supply cables. Viewed from the financial standpoint it is often found that the return to be expected is totally inadequate to justify the heavy outlay that would be entailed in looping in the ring-main cables. The portion looped in must be of course of the same carrying capacity and sectional area as the ring-main cable, and that being so, the sectional area would be out of all proportion to the prospective load. Under these circumstances the supply authority requires to exhaust every possible economical method of distribution in order to fulfil its obligations and ensure at the same time an adequate return on the capital employed.

The problem is somewhat simplified by running a single extra-high-tension branch service from a switch-house situated on the route of the ring-main cable. By so doing, the cost of a loop-in can be saved; but unless the route length of the service is fairly considerable, this advantage is largely discounted, if not entirely eliminated, by having to equip a switch-house at the point of junction.

In a number of cases the power supply required is too small to justify the cost of even a single branch with switch-house and consumer's sub-station equipment. Such cases can often be met, however, by the installation in lieu of the switch-house of an extra-high-tension junction box; and as a matter of fact this course has been successfully adopted by the author during the past eight years.

The following table gives some indication as to the percentage cost of various methods of delivering a supply of say 100 kw. to a point distant, let us assume, one mile from the line of route of a ring-main cable, it being understood that the point of supply is so far removed from any transforming station that a low-tension service line is not considered to be economically practicable.

(a) Cost of looping in ring-main cable, auxiliary cables, and consumer's sub-station equipment	100
(b) Cost of laying branch cable and auxiliary cables, building and equipping switch-house, and equipping consumer's sub-station	64
(c) Cost of laying branch cable and auxiliary cables, link box, and equipping consumer's sub-station	53

The percentages are calculated for underground cables in each case. In the case of (a), overhead transmission is not admissible, as the expense of a double line built in accordance with Board of Trade requirements and accepted modern practice would show to very little advantage compared with underground cables laid in a

link box at the point of junction. The results achieved with these boxes have been so uniformly successful that in the author's opinion the time has now arrived when a description, together with an account of the method of application and operation, should be published for the benefit of those members who may be specially interested.

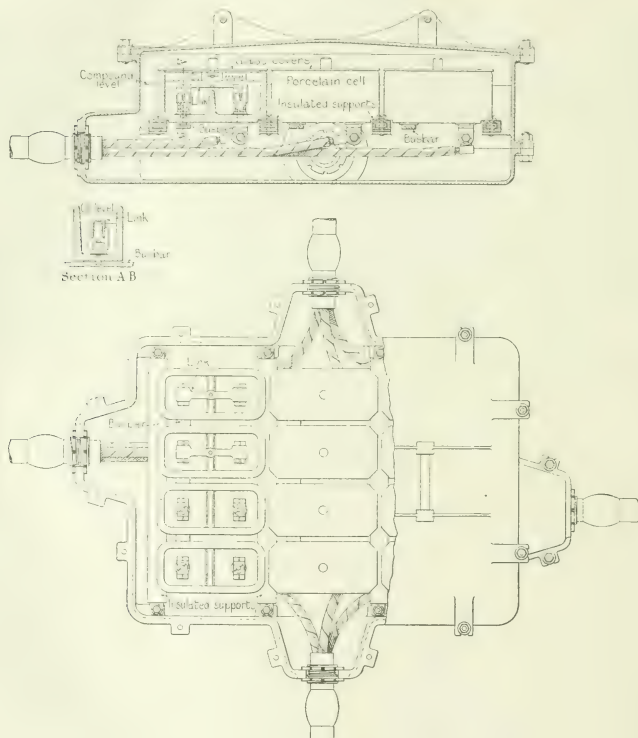


FIG. 1.

common trench. Overhead transmission is, however, often quite admissible in the case of (b) and (c), and if adopted would make the percentage cost of these two methods still more favourable.

These figures show at once the economy in first cost in using branch services controlled from an extra-high-tension

Specifications and preliminary sketches clearly defining the functions and conditions to be met were submitted in 1907 to the principal manufacturing firms throughout this country. At that time the application of link boxes to 11,000-volt circuits was considered to be so daring that one or two firms declined to tender, and were good enough

to give a friendly warning against the dangers underlying such an experiment. Fortunately, however, Messrs. Siemens Brothers submitted a design which clearly fulfilled all the requirements of the case, and which provided in the author's opinion a reasonable margin of safety both as to the insulation of the current-carrying parts and as

a very important feature and is a point frequently overlooked in link-box design. In many cases the links or fuses are so arranged that it is quite impossible for any person unprovided either with a most retentive memory or a diagram of connections to know exactly what the effect may be in manipulating them. It ought, in the author's opinion, to be accepted as a fundamental principle, that all disconnecting boxes should embody in their design their own diagram of connections, thus leaving no doubt as to the route and purpose of each cable entering them.

The link box consists essentially of a rectangular cast-iron box in three portions, so arranged as to facilitate assembling and jointing. The internal fittings consist of a number of porcelain cells, one for each cable core. Details of one of these cells are shown in Fig. 2. Through the bottom of the cell pass two studs, one of which is in metallic contact with a busbar, and the other is directly connected with one of the cores of the cable. To these studs are attached two main contacts, and these again are connected together by means of a removable link. The porcelain cell is of a suitable depth to provide for the link being immersed in oil. Each cell is provided with a glass cover, and in the centre of each link is a screwed hole into which the operating rod is screwed when the removal or insertion of a link is either necessary or desirable. These cells are assembled in groups corresponding to the number of phases, and they are imbedded in the box compound with which the greater portion of the cast-iron box is filled.

Referring to the cast-iron box itself, the bottom joint passes through the main cable glands, and the faces are machined and fitted throughout. This arrangement provides the maximum of accessibility, in so far as that it allows of all the cable cores being set into position and jointed up before the box is finally assembled, and when this is done nothing remains but carefully to "wipe" the lead of the cable to the brass glands of the box.

The complete jointing of one of these boxes occupies too much time to permit of all the work being done at the site. Obviously the ring circuit would require to remain open all the time this work was being carried through, and that being so, the risk has to be taken of another section of the main opening under fault conditions, thus endangering supply to a more or less extensive area. This difficulty is got over most conveniently by jointing into the link box short lengths of cable of the required sectional area. This work can obviously be done either at the power house or at the nearest available depot. After assembly the box is transported *en bloc* to the required site, where two or more cable jointers make the requisite straight joints in the minimum of time.

These boxes are not intended to break load, but simply to disconnect a line under pressure. As a matter of fact in one or two cases of emergency a connection has been both broken and made under load, but the carrying out of this operation demands a cool head and a steady hand, the flash and noise when the circuit is either made or broken under these conditions being considerable.

Special care has in all cases to be taken to eliminate any traces of moisture inside the box, and this is done by means of an exterior vessel containing calcium chloride. This exterior vessel is directly connected with the box by

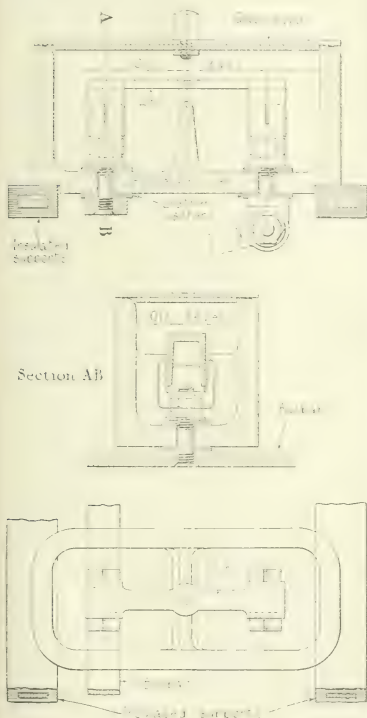


FIG. 2.

to that most important consideration, the safety of the operator. The design submitted was, subject to a few modifications, the one finally adopted by the power company with which the author is connected.

The general arrangement of the link box is shown in Fig. 1. Each main and service cable is brought into the box in such a manner as to leave no doubt in the mind of the operator as to its identity. This condition is obviously

means of a short piece of screwed tubing, so that the chemical can be renewed when required without the necessity of opening the box cover.

In the construction of the box chamber, every care must be taken to exclude surface or drainage water. The chamber therefore usually consists of a shallow pit built of 9 in. brickwork on a 6 in. bed of concrete, this brickwork being surrounded by a  $4\frac{1}{2}$  in. brick wall so placed as to leave a space of 1 in. or more between the two walls. This intervening space is filled with bitumen run in hot, and thus ensures a perfectly dry chamber under all climatic conditions. Care has also to be exercised to exclude moisture when opening the box, particularly in damp weather, this operation being carried out under a jointer's tent.

It has been found in practice to be quite feasible to take branch services off sections of cable controlled with balanced protective gear. At first sight it might appear that the taking off of such intermediate services would disturb the static balance in the current-transformer secondary circuits. Theoretically this is undoubtedly the case, but when it is borne in mind that in actual practice the relays employed in connection with a balanced protective system are usually set for operating on a fault current of from 60 to 200 amperes, it will at once be apparent that there is an ample margin within which it is possible to give a branch supply without materially impairing the efficiency of the protective system. Nevertheless it has been found necessary to install a no-volt release at the supply or consumer's end of such service branches, as otherwise the static balance is liable to be disturbed in the event of any sudden fluctuation of voltage, caused for example by a fault on the external circuit.

Supplies given off these service branches are subject to the disadvantage that they are liable to temporary interruption if a fault should occur on that portion of the ring-main circuit off which the branch is tapped. This is, however, not a serious objection, as it is a simple matter to test out, disconnect the faulty section, and restore supply over the sound portion of the ring main. Obviously it is in this connection that the disconnecting links are of special value.

As an example of practical application attention is directed to Figs. 3 and 4. The former shows a 4-way extra-high-tension link box having two service branches; one service conveys a supply to a brick-works and the other to a bridge-building works. Owing to the gradual growth of the supplies referred to, and also to the general development in the immediate vicinity, it became necessary to supersede the link box with a switch-house equipment. Fig. 4 shows the ultimate grouping of the same circuits.

This example, one of many, shows the adaptability of such a device for development purposes. In this particular case there can be little doubt that had it not been possible to give these two supplies by means of service branches, both supplies would have been most difficult to arrange, as the initial revenue from them could not have yielded the company a reasonable return on the capital outlay involved in either looping them on to the ring circuit or supplying them from a fully equipped switch-house built on or near the route of the ring-main cables.

It will be readily understood that in a widely scattered industrial area the field for such applications is fairly extensive. These branches are often extended from time to time for miles, continuing from one point of supply to another until in the ultimate course of development it is found practicable to reconnect the far end either with another similar branch or with another point on the ring circuit, the branch ultimately becoming part of a sub-



FIG. 3.

sidary ring. The original box is then withdrawn and a switch-house substituted in its place. It is quite clear that, with development carried out in such a manner, it is possible to make each extension on a minimum of capital outlay, the supply network by a process of steady growth being extended over a wider area to the mutual advantage of the industrial community and the supply authority.

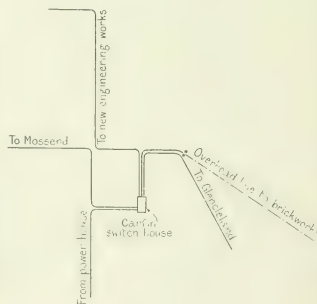


FIG. 4.

A duplicate service implies complicated switchgear arrangements and the introduction of parts liable to go wrong or cause trouble. The introduction of balanced protective systems, and indeed all forms of discriminating cut-outs, may be regarded as an eloquent commentary on the fallibility of electrical equipments and as an expression of the desire of engineers to obtain greater reliability.

One of the chief sources of reliability is simplicity, and the author is a confessed advocate of the single branch service as the most direct method of securing reasonable freedom from failure for all classes of supplies, except those the magnitude or importance of which makes inclusion on a ring circuit imperative. All such service branches should, in every case, be laid complete with the necessary auxiliary cables for a telephone service and pilot wires, so as to permit of the steady development of the branch in the direction already indicated.

In connection with the present European crisis, sundry war service supplies have been given from these link boxes, this course being dictated by the extreme urgency of the demand and the difficulty in obtaining deliveries of switchgear owing to manufacturers' work coming under Government control for the manufacture of munitions. These services have been maintained under the most onerous conditions without the slightest interruption, and have proved themselves to be entirely satisfactory from every point of view.

It is of course not contended that these link boxes are applicable in every instance, but it is undoubtedly the case that their use makes it possible to secure business which would otherwise be most difficult to negotiate.

A demand sometimes arises for small lighting and power supplies for farms or residential property along the route of overhead transmission lines. There is a growing tendency to make the granting of wayleave facilities, especially through residential estates, conditional upon the giving of

a lighting supply to the owner's house. Where such a condition has been imposed it can be very readily met in the case of a low-tension transmission line, but in the case of an extra-high-tension transmission the solution is not so simple. The author has met the difficulty by using small pole-type transformers. One form of these was manufactured in the United States, and is specially designed for use as a pole transformer, having weather-proof terminals, etc. Nevertheless it has been deemed inexpedient to expose the casing to the rigours of a Scottish winter, and a protective covering is therefore provided. The transformer shown is of 3 kw. capacity and weighs 450 lb. Its ratio is 11,000/400, and provision is made for a low-tension 4-wire supply on the secondary side. A set of extra-high-tension fuses are interposed between the transmission-line conductors and the transformer.

There does not appear to be any specific reason precluding the use of larger units of, say, 50 k.v.a. The reliability of transformers of this type has been fairly well established. Personally, the author would have no hesitation in undertaking such a supply should opportunity occur, as he is fully persuaded that no effort should be spared to create and develop a demand for electrical energy on the part of the small power consumer. No scheme of electrical power distribution may be considered complete which finds no place in it for the small trader or the ambitious workman who desires to become his own master. Only by such means can an appropriate place be found for electricity in the service of man.

## DISCUSSION.

Mr. R. B. MITCHELL: I am in complete agreement with the author as to the usefulness of these junction boxes under conditions where the revenue to be derived would not warrant any considerable capital expenditure. The taking of branches off high-tension loops is now recognized to be quite good practice. In Mr. Beard's recent paper,\* in the diagram of the distribution system on the North-East coast it was shown that quite a considerable number of branches were taken from loops, and in one or two cases a Tee branch was taken off another Tee. I know that they do not use these junction boxes. They may use switch-houses such as the author has described, but of course a large proportion of the system operates at 20,000 volts and junction boxes would not be so satisfactory at that pressure as they are at 11,000 volts. In Glasgow, following the Clyde Valley Company's lead, we have used these junction boxes for some years. We have eight in operation and another being installed, and they give complete satisfaction. I am glad to say that we have not had to open these boxes in an emergency during the whole time they have been in use, and in that respect we are unable to say what their performance would be. The general arrangement, as the author has said, is very simple. The identification of the different parts should be easy, and not only should the individual cables be identified easily but also the busbar contacts in relation to the cable terminal contacts. In the illustration (Fig. 1) on page 640 the positions of the busbars are in proper sequence, but

I think the busbars on phases 1 and 3 should be kept always to the outside of the box in order to get longer bends on the cores to the cable terminal contacts, which would then be towards the inside of the box. With regard to the identification of the busbars, I have thought of fixing to each bar a piece of porcelain which would project up through the compound. We have not found the assembling of the box in a workshop to be a success. The conditions in Glasgow may be different to some extent from those experienced by the Clyde Valley Electrical Power Company in the country. They can put down a box with all the tails laid out in a country road, but in a crowded thoroughfare this is not possible. We have always to contend with gas and water pipes, and when all the tails are connected we may have to thread the cables underneath these conduits, thereby subjecting the cables to severe strains. I do not altogether agree with the author as to the time lost in assembling a box in situ. It is unnecessary to interfere with the loop until the tails are laid out and those which will ultimately connect the loop are laid alongside of the main cable; then after everything is connected up it is easy to disconnect the loop section and make these two joints, the total time during which the section is dead being merely that necessary for making the two joints. I consider it to be most desirable that facilities should be provided for earthing the cables at the box. Suppose that a fault exists on the branch leading from the box; the links would be drawn in the box on that cable, but the busbars would be kept alive. After the faults had been located it is likely that a joint or joints would require

Mr.  
Mitchell.

\* "The Design of High-pressure Distribution Systems," *Journal I.E.E.*, vol. 54, p. 125, 1916.

Mr. Mitchell.

to be made, and it is then desirable that the faulty cable should be earthed if possible in the box and also at the other end. The jointer is quite satisfied if he knows that the cable is earthed at both ends. I wish to show a very simple and safe device which enables this earth connection to be made in the box. It is done by substituting for the lid of each cell another lid of porcelain with a fitting attached, which when the lid is placed in position makes contact with the cable terminal contact. The fitting is connected on the outside of the lid by a length of insulated conductor to an earthing stud on the side of the box. The use of this device makes the identification of the busbars all the more important. Also the cable terminal contacts must be accessible when identifying the phases preparatory to making the joints, and this would be a dangerous proceeding with the busbars alive unless the tester were absolutely clear as to the position of the live terminals. The use of the earthing device connections already described enables the phasing to be carried out in perfect safety. The author refers to the advantages of the use of calcium chloride. We have never used it, and have not so far had any trouble through omitting to do so. I note that the author has provided a space between the two walls of brick and I think this is an excellent idea. I should like to ask him if he has had any trouble due to the covers on the cells being made of glass. When we have inspected our boxes some time after they have been put in place, we have found a number of the glass lids broken owing to temperature changes. Could not the glass lid be replaced in future with a porcelain lid? The author's reference on page 642 to the no-volt release rather puzzled me and I intended to ask him how it should be used, but he has covered this point when reading the paper. He mentioned that the surges which take place on the system make the fitting of a no-volt release necessary.

Mr. Nairn.

Mr. W. NAIRN: When I first learned some five years ago that such boxes as that described by the author were in use I certainly considered that their operation would cause the staff grave concern, but during this period not a single failure has occurred and I have been completely converted as to their efficiency, and believe them to be quite as reliable as any other part of the distribution switchgear. I think it says a great deal for the original design of this box that it should have been successfully operated for so many years and at the present day it has not been thought necessary to amend the original design in any way. This is certainly not the usual experience of pioneers in extra-high-tension switchgear design. The small 3-kw. pole transformer described on page 643 is in this country an innovation of more than passing interest. Extra-high-tension transmission lines run entirely through agricultural districts, and the proprietors or farmers are naturally interested to learn that these lines are capable of supplying some thousands of horse-power, but if the lines cannot supply them with a few lights for their houses or power to drive a small agricultural motor their interest soon wanes and they come to regard the lines as neither ornamental nor useful. The use of the transformer described by the author should give to these line wayleaves a permanency they might not otherwise command. The transformers seem to be well designed to stand the rough weather conditions to which they are subjected. On page 641 near the top of the second column the author states that

in his opinion "all disconnecting boxes should embody in their design their own diagram of connections." There is no doubt that this is a point of paramount importance, not only in the design of junction boxes, but also in the switchgear lay-outs in the sub-stations. Stonework partitions between feeders should differ considerably from the stonework partitions between the phases of the same feeder; isolating links should be placed immediately over and under the oil switches they control; remote-control handles should be arranged symmetrically opposite the oil-switches; and generally the whole design should be arranged as its own diagram of connections, as the author points out.

Mr. D. A. STARR: The author showed a view of some Canadian transformers enclosed with housing. I do not think there is any Board of Trade regulation which insists that such transformers should be protected in this way. I presume the author has not yet acquired such full confidence in this type of outside transformer as engineers in Canada have. In Canada I have seen thousands of such transformers connected on pressures much higher than 11,000 volts (the pressure used by the Clyde Valley Company), and these transformers erected on poles had no cover or housing at all. I presume that the housing provided by the Clyde Valley Company is merely to protect the fuse, and is a luxury which has been added for the protection of the system in case accidents should happen on one of these branch circuits.

Mr. W. B. HIRD: From my experience of what happens in boxes at pressures as low as 500 volts when a circuit is broken inside the box, it appears wonderful that anyone should attempt to remove or replace links inside a box at 11,000 or 20,000 volts. Mr. Starr has referred to transformers used in America without any protection. The fact that protection is found necessary here, emphasizes the fact with which we must all be familiar, namely, that the success of any particular piece of apparatus, or even of any particular method of design or construction is not necessarily successful in this country because it has been found good in other parts of the world. We must all have come across many instances of this kind. One which I particularly remember was of a special make of arc lamp which burned quite successfully in the open air on the Continent with very slight protection, but which was a complete failure when exposed to the climatic conditions of Scotland. The moral seems clear, that slavish imitation of foreign methods, although no very apparent difference exists in the conditions, only leads to failure, and that careful consideration and experiment is required before attempting to transplant such methods.

Mr. J. K. STOTHERT: I can recall some experiences Mr. Starr which will interest the author. In 1895 I had to superintend the laying of mains in one or two towns. The pressure was only 2,500 volts and we used single-phase transformers. It was before the days when transformers were immersed in oil. We put the transformers in the streets in cast-iron boxes and we had a good deal of trouble due to dampness. We got over many of our difficulties by using receptacles filled with chemicals, and we tried calcium chloride and caustic soda, ultimately preferring the former. The heating up of the transformers inside the street box rendered it difficult for us to keep the joints intact. The joints illustrated on the screen would never

other. have done. We had to use thick flanges and good jointing material to keep the joints damp-proof. We fitted a pressure gauge in the lid of the street box and found that the pressure inside the box was considerable. In some of the brickwork boxes we used a double wall, as indicated by the author, and we filled in the space between, not with bitumen compound, but with street asphalt; the results were very satisfactory.

Mr. A. P. ROBERTSON: I should like to ask the author whether it is necessary to change the calcium chloride very frequently. Mr. Mitchell says he does not use any chemical. Is it necessary to use calcium chloride at all if the joints are well made and the box dried out with a vacuum, as is done with telephone cables? Would not that be satisfactory?

Mr. B. B. GRANGER: What precautions does the author take to prevent the pits containing these junction boxes flooding?

Mr. R. A. BROWN: I should like to know the size of the pit and the containing frame necessary for these link boxes. On the system I have charge of there are several single branches off the ring main, and I have always found it necessary in the past to build a switch-house on each branch, as most of our cables run down narrow streets with a pavement width of 5 ft. to 6 ft.; in my opinion it would be quite impossible for a disconnecting box to be put under such a pavement, crowded as it usually is with water and gas pipes.

Mr. H. T. BURTON: A previous connection with the power companies of the South, where link boxes and even Tee joints on high-tension work are not regarded with favour, led me to be rather pessimistic regarding the efficiency of a link box on a 11,000-volt system, but I have been converted in regard to their utility and operation. The development of the high-tension service, I think, lies in the overhead line, when the inconsistencies both of our wayleave laws and our legislation have been changed. The American system of lattice poles, overhead switching apparatus, and overhead transformers, will be as common on our highways and railway lines as telephone lines are to-day. Outside transformers are in more common use in the South than they are here, and four years ago I supervised work on a 6,000-volt 50-k.v.a. transformer which was mounted on a 4-membered pole without weather protection and gave satisfactory service. Owing to his long experience the author's views as to high-tension services equipped with the Merz-Hunter system of protection would have been interesting.

Mr. D. M. MACLEOD (*in reply*): In reply to Mr. Mitchell I should not like to put forward these boxes for use on a 20,000-volt circuit, but doubtless the design could be altered to render them adaptable for such conditions. Regarding the identification of the busbars, the usual method is to indicate the position by painting the busbar end of the porcelain cell with some distinguishing colour. I am much obliged to Mr. Mitchell for drawing attention to the apparatus used in Glasgow, and, with his permission,

Mr. Macleod. I should like to adopt this feature as it conveys an added sense of security to the operator. Regarding the trouble which Mr. Mitchell has experienced with the cracking of glass covers, I have had no such unpleasant experience, and can only suggest that these breakages may be caused by the binding nut securing the two glass plates together being too tight. Mr. Mitchell's difficulty in jointing up these link boxes in a busy thoroughfare is one which can be easily understood. This trouble can be readily met by selecting the nearest available side street for the site of the box, and I invariably follow this course under such conditions or where the accommodation on the footpath is insufficient.

In reply to Mr. Starr, the house over the pole transformers is in my opinion necessary to protect the fuse porcelains and leading-in porcelains from damage caused by malicious stone-throwing.

Mr. Nairn rightly calls attention to the fact that the presence of the pole-type transformers on overhead transmission lines gives a degree of permanence to the wayleave which it might not otherwise possess.

Regarding the point mentioned by Mr. Hird as to the danger involved in operating such boxes, the use of a dry wooden pole gives confidence. As an additional protection, rubber gauntlets are sometimes, though not always, used. During all the years which these boxes have been in operation there has been no mishap of any kind.

I was greatly interested in the points raised by Mr. Stothert in his reminiscences relating to the troubles experienced by the pioneers of the electrical industry.

Referring to Mr. Robertson's query, the use of calcium chloride is not absolutely necessary, but in my opinion it is a wise precaution to take so as to guard against any danger of sweating or possible negligence on the part of the operating staff in not properly sealing down the box cover.

Mr. Granger asks what provision is made for keeping surface water out of the pits. This is most readily done by "pointing" the box frame and cover with plastic cement, of which there are several brands on the market yielding very good results.

Referring to the point raised by Mr. Brown, the size of pit employed is approximately 4 ft. square—inside measurement.

Mr. Burton's observations are very interesting, and point in the direction of the probable future development of outdoor switchgear in this country. The chief danger to which such apparatus is exposed is the risk of mechanical injury through malicious mischief. I am afraid that these link boxes would not be at all suitable for use with circuits provided with the Merz-Hunter system of protection, which involves the use of a split conductor. To adapt these boxes to such a system would imply the use of duplicate busbars and duplicate links, and this would entail a degree of complication against which it would be difficult to make provision inside the necessarily limited space of such boxes.

## THE ECONOMICAL PRODUCTION OF POWER FROM COKE-OVEN GAS.

By G. DEARLE, Associate Member.

*(Paper received 29 October, 1915, and read before the YORKSHIRE LOCAL SECTION 10 May, 1916.)*

In collieries where a proportion of the output of coal is converted into coke in either waste-heat or regenerative ovens, there is always a certain surplus volume of gas of high calorific value which is available for the production of power. In the case of the regenerative type of coke oven the volume of gas thus available is much greater than in the older pattern of waste-heat oven, and it is partly for this reason that the majority of new coke-oven installations during the past few years have been of the regenerative type.

The advantage of regenerative ovens is that the whole of the surplus heat in the coal is produced in the form of a combustible gas instead of merely as a waste-heat product. This combustible gas can be used to much greater advantage than the waste-heat product, for by utilizing it in gas engines it is possible to develop 3 to 4 times the power that can be obtained from the use of waste heat under boilers. There is also an advantage in being able to convey the gas any distance without deterioration, which is not possible in the case of the waste heat where the boilers must be installed quite close to the coke ovens.

The choice of this successful utilization of the waste gas in its most productive form is one that interested the author for many years before the opportunity occurred for him to demonstrate its possibilities, and there is no doubt that this problem appeals to almost all engineers to-day, though many of them still remain unconvinced that the large gas engine has proved itself economical and reliable in service. Many and varied were the troubles predicted for the author by engineering friends when it became known to them that the responsibility of the running of a gas-driven power station was to constitute one of his duties. It is, however, very pleasing to be able to state that none of these dismal prophecies have been fulfilled, whilst the views of the very few who were optimistic of the success of the plant have been more than justified, and in the course of the past three years the author has had frequent occasion to wonder why the large gas engine has not been more widely adopted as the prime mover at collieries and other installations where waste gas is available. A great deal of prejudice exists amongst a certain class of engineers against the use of gas engines for large power work. With the exception of perhaps those few who have had the unfortunate experience inseparable from the development of a type of prime mover which, after all, has only been produced in a commercially operative form for large power purposes during the past 15 years, the author is satisfied that such prejudice is born primarily of lack of experience of what can be done with a gas engine designed on modern lines.

The principal objections raised by opponents of gas-driven power plant are:—

- (1) The unsteady turning moment.
- (2) The difficulty of starting the engine.
- (3) The general absence of reliability in operation.
- (4) High cost of maintenance.

In this paper the author hopes to show from his personal experience with a modern gas-driven electric station operating under conditions which may fairly be described as severe for any type of power plant, that such objections are without foundation in the case of an installation put down on sound engineering lines.

It is only fair to assume that any class of efficient power plant requires reasonable and regular attention in order that the best results may be attained, and it will be noted from the figures given later in the paper that in the case of this gas-driven station neither the labour required for operating the plant nor the cost of maintaining the same is in the slightest degree excessive when consideration is given to the service which it performs.

The installation under review consists of three 500-b.h.p. vertical tandem gas engines direct-coupled to 3-phase alternators, generating current at a pressure of 440 volts and a frequency of 50 cycles per second.

The gas engines are of the single-acting type operating on the Otto or 4-cycle principle, the cylinders being so arranged in tandem that the suction stroke of one cylinder is the explosion or working stroke of the other cylinders on the same line. By this arrangement each crank receives one impulse per revolution, each down-stroke being a working impulse of either the upper or the lower cylinder. On the up-stroke the inertia of the moving parts is absorbed by the compression of either the top or the bottom cylinder, and part of the inertia is absorbed on the downward stroke by a buffer cylinder formed under the upper piston.

By means of this arrangement the connecting rod is always in compression and little or no strain is thrown upon the connecting-rod bolts. This is an important feature, as according to the reports of the various insurance companies more breakdowns to engines are caused by the failure of these bolts than by any other cause.

The number of impulses which the shaft receives, together with the influence of the buffer cylinder, renders the turning moment of the engine equal to that of a high-speed steam engine. In the case of the 4-crank 8-cylinder engines under consideration, running at 300 r.p.m. with cranks at 90°, the shaft receives four impulses per revolution or 1,200 impulses per minute, so that with a comparatively light flywheel the cyclic variation is less than one-third of 1 per cent, which is sufficiently even for the

paralleling of the alternators without the slightest difficulty. This disposes of the first objection, viz. that the turning moment is unsteady.

Of course the turning moment of a single-cylinder low-speed engine is unsteady, since such a machine may only receive 60 to 80 impulses per minute; and to run alternating-current machines in parallel with such engines is practically an impossibility, as the weight of flywheel required to obtain anything like an even turning moment would be prohibitive.

There are eight cylinders on each engine, the four upper ones having a diameter of  $16\frac{1}{2}$  in. and the lower ones  $15\frac{1}{2}$  in., with a stroke of 16 in. The speed of the engine is 300 r.p.m., and the full load is 500 b.h.p. The object of making the upper cylinders 1 in. larger than the lower ones is so that the whole line of pistons may be removed together. By this arrangement the dismantling of the engine for cleaning purposes becomes very simple and the time usually taken for the removal of a line of pistons and the cleaning and replacement of these is from 6 to 10 hours, but if the engine is urgently needed this work can be carried out in 3 to 4 hours. A considerable saving of time is effected by having a spare line of pistons, as the cleaned line can be dropped in as soon as the other is taken out, thus avoiding the loss of time waiting for the line to be cleaned and overhauled.

The lubrication of the engine is effected by means of plunger pumps working from an eccentric on the crank-shaft, these pumps drawing the oil from the well of the crank-case through strainers. These strainers are in duplicate and are so arranged that it is possible to remove one strainer for cleaning purposes whilst the engine is running, the action of removing it automatically closing the valve and thereby preventing any unfiltered oil getting into the lubricating system. As soon as the strainer is replaced this valve is automatically opened again. The oil passes from the pumps through coolers and so to the various bearings of the engine. The oil coolers are arranged outside the engine, and the whole of the circulating water for the engine first passes through these coolers. By this means the oil is kept at a fairly low temperature. The normal oil temperature at the inlet of the cooler is  $74^{\circ}$  C., and the temperature at the return to the crank-case is  $45^{\circ}$  C. This temperature will vary, of course, with the atmospheric temperature and also with the nature of the oil used, a heavy oil naturally retaining the heat longer than one of a lighter body. The oil is pumped to the main bearings of the crank-shaft and then through passages drilled in the crank-shaft to the crank-pins. From the crank-pin the oil is again led up to the gudgeon pin. The bearings of the cam-shaft are under forced lubrication, and the valve tappets, rollers, and pins are also fed from the same system. The pressure of the oil may be varied by means of a by-pass valve situated on the crank-case close to the pressure gauge recording the pressure of oil in the system, the usual working pressure of the oil being from 10 to 20 lb. per square inch. The top cylinders and piston rods are lubricated by means of a separate sight-feed lubricator mounted on the crank-case and driven from the cam-shaft. A separate pump to each point renders this lubrication absolutely certain.

The ignition is obtained by means of a magneto and transformer coil. The sparking plugs are of a very heavy

design and mica insulated. A stand-by ignition is provided in the shape of an accumulator which is switched on to the coil by means of a change-over switch, but this is only used for testing the ignition, as no trouble has been found in starting direct from the magneto.

The engine is started by means of compressed air, which is stored at a pressure of 300 lb. per square inch in a series of six storage tanks mounted outside the power house. Each of these tanks when fully charged is capable of giving five starts. The air is compressed by means of 2-stage compressors, and these are arranged in duplicate, one being driven by a motor and the second by a small gas engine drawing its supply of gas from the same main which feeds the larger engines.

The cooling water from the engine is pumped over a double-drip natural-draught cooling-tower designed to deal with 36,000 gallons of water per hour and to reduce the temperature of this from  $135^{\circ}$  F. to  $80^{\circ}$  F., with an atmospheric temperature of  $80^{\circ}$  F. The water supply is circulated by means of a Rees Rotorbump pump delivering 12,000 gallons per hour against a head of 52 ft. This pump is driven by a 15-h.p. squirrel-cage motor. Stand-by sets are provided in the form of a separate 3-in. pump to each engine, each pump being driven by an 8-h.p. squirrel-cage motor running at 1,400 r.p.m.

It is of course essential that the water used should be reasonably free from impurities and an excess, say not more than 15 per cent, of hardness, and it is also important that the tank of the cooling tower be kept free from grease and oil. Cleaners very often have a bad habit of dipping oily buckets into the cooling tank for washing purposes, and, unless the practice be stopped, it is surprising the amount of oil which will get into the water circulation from this source. The grease cups on some types of circulating pumps also contribute to this cause.

A certain amount of coal dust is always present in the circulating water of a colliery power-station, but the application of a powerful hose to the hand holes of the jackets about every three months is sufficient to keep down this trouble, provided that the jackets are designed, as they should be, to facilitate flushing.

The ventilation of the crank-cases of the engines is effected by means of 3-in. pipes coupled to the top of each crank-case and carried outside the engine-house, terminating at the top of the exhaust pipe above the silencers. By placing the outlet of this ventilation pipe concentric with the outlet of the exhaust, an ejector action takes place, which effectually scavenges the crank-cases and prevents any accumulation of gas or oil vapour such as would be likely to cause an explosion in the crank-case.

The ventilation of the engine-house is effected by a 30-in. motor-driven fan, and though this somewhat aggravates the coal-dust nuisance, it is of great service in keeping down the sulphur fumes and thus protecting the exciter, commutators, etc.

The gas supply is obtained from a battery of 110 Otto ovens; 60 of these are waste-heat and 50 are of the regenerative type. From the former about 15 per cent of the total gas is available, and from the latter about 40 per cent.

After all the by-products are removed, that is after the gas has passed the benzole scrubbers, the gas is drawn to the engines by means of a steam-driven exhauster of

60,000 cubic ft. per hour capacity. This exhauster is governed by a diaphragm governor controlled by the pressure of the gas in the main at the engine stop-valves. An electrically-driven exhauster is installed as a stand-by, and this is controlled from the power-house switchboard and is capable of dealing with 30,000 cubic ft. per hour. This exhauster is driven from a 10-h.p. motor by means of a silent chain-drive. A further steam-driven exhauster is, however, to be installed, as the electric exhauster is found to be scarcely large enough for the work during peak loads.

The quantity of gas passing to the engines is measured by means of a rotary meter, and the gas pressure at the stop-valve is registered on an illuminated-dial pressure-gauge in the power house. The average gas pressure is approximately 10 in.

The further purification of the gas after it leaves the by-product plant is a most important item, and it is surprising that the question of gas purification should be treated by prospective purchasers of gas power-plant—and even by some makers—with such scant consideration. When steam-driven plant is installed, no hesitation is shown in providing for water softeners, economizers, and the lagging of steam mains, yet when a gas-engine-driven plant is considered, the purifier appears to be looked upon as almost a luxury, and in this very reason we may find some of the failures of gas-driven plant.

When the gas leaves the benzole scrubbers it contains about 900 grains of sulphuretted hydrogen in every 100 cubic ft. If this sulphur were allowed to go through the engines a considerable amount of trouble would be experienced. In the first place, when the engine is shut down a certain amount of the exhaust gases is left in the cylinders and pipes; the moisture in this gas condenses as the engine cools down, so that the sulphur would immediately form sulphurous acid. This would, of course, attack the inside of the cylinders and the exhaust valves.

A further effect is that the presence of sulphur appears to cause a certain amount of pre-ignition, or spontaneous ignition, of the charge during the compression stroke. A possible reason for this is that the presence of a small portion of the sulphuretted hydrogen acts as an igniter, this sulphuretted hydrogen being more liable than the rest of the gas to spontaneous combustion under compression. It will therefore be seen that it is of the utmost importance to remove as much of this sulphur as possible.

The gas is therefore purified by oxide of iron in a set of four purifiers of the Wilbourn type, each 20 ft. square by 5 ft. deep. The boxes hold about 30 tons of oxide in two tiers on ordinary grids. Two classes of oxide—"Lux" and "Bog"—are used. These boxes are worked on what is known as the "backward rotation" principle. Air to the extent of  $2\frac{1}{2}$  or 3 per cent is drawn in at the exhauster, and this air supply plays a very important part in the revivifying of the oxide in the purifiers. Prior to the introduction of this air feed to the main, the oxide in the purifiers was changed at the rate of one box every four weeks. After the introduction of the air the period between changing the oxide was extended from four weeks to four months, thereby producing a very considerable saving in the cost of generation.

In order to check the amount of air flowing into the

exhauster, it is passed through a small rotary meter. The spent oxide after being taken from the boxes is revived by being spread out and exposed to the air. When this oxide is no longer capable of taking up any further sulphur, a ready market is found for it, the present value of oxide containing 50 per cent of sulphur being £2 per ton, and the revenue thus obtained pays for the oxide and the cost of labour on the purifiers.

After the gas has passed through the purifiers it is taken to the engines. Its average composition is:—

CO <sub>2</sub>	...	...	...	...	3.6	per cent
C <sub>2</sub> H <sub>4</sub>	...	...	...	...	2.6	"
CO	...	...	...	...	7.6	"
O	...	...	...	...	0.3	"
H	...	...	...	...	50.2	"
CH <sub>4</sub>	...	...	...	...	30.1	"
N	...	...	...	...	5.6	"

The calorific value of this gas varies between 500 and 550 B.Th.U., the average value being 520 B.Th.U. The total sulphur contained in the gas after passing the purifiers is less than 50 grains per 100 cubic ft., and a further advantage of the purifiers is that they absolutely eliminate the last traces of any tar which may be left in the gas after passing the benzole scrubbers. This freedom from tar is of considerable benefit to the engine, as trouble from valve sticking is absolutely unknown and not the slightest trace of tar has ever been found in the engine.

The current from the generators is delivered to a 13-panel switchboard, consisting of one voltage-regulating panel, three generator panels, one summarizing panel, and seven outgoing feeder panels. A testing panel is also included in the power-house equipment, and suitable means for testing motors up to full load is provided by means of a "Walker" air-brake dynamometer.

The motors connected to the mains aggregate approximately 1,700 h.p. and operate the whole of the coke-oven machinery, the fans, haulages, belts, shakers, fitting shops, saw-mills, etc. The lighting load connected averages about 70 kw. The daily load on the station reaches peaks of 1,050 kw., and the average load during the 24 hours would approximate 580 kw. The station is running continuously, seven days per week.

The foregoing will give some idea of the type of plant and its conditions of working, and the author now proposes to deal with some of the results obtained and the methods employed in the running of the plant.

During the initial running of the plant some trouble was experienced due to the difficulty of obtaining satisfactory mixing of the very rich gas and air. The result of the poor mixing was a certain amount of overheating, but this trouble was soon entirely overcome. A usual method of dealing with this has been to dilute the mixture with a certain amount of exhaust gas. This method has always appeared to the author to be somewhat inefficient and was not resorted to. The main gas-pipe to each engine was reduced for a distance of about 10 ft. to an internal diameter of  $2\frac{1}{2}$  in., and on reaching the engine was led into the mixing chamber for a distance of about 6 in. Entering the mixing chamber at right angles to this pipe, and about 3 in. above its end, was an auxiliary air supply, controlled by a diaphragm governor. The gas admitted to the mixing chamber was then diluted here by

a certain quantity of air. A further air supply, controlled by a hand lever from the driving platform, was led direct into the chamber of the governor valve, where the diluted gas and air met. After passing through the chamber of the governor valve the mixture was given a rotatory motion by means of a set of vanes, and was also very thoroughly mixed by being passed through a set of perforated plates. With this device no overheating or pre-ignition is noticed, and the engines can be run up to and above their rated capacity without trouble.

The exhaust gases are analysed at stated times or as the need arises, and the percentage of carbon monoxide is noted. The result aimed at in the analysis of the exhaust gases is to obtain an excess of air, consistent with the engine giving its full power.

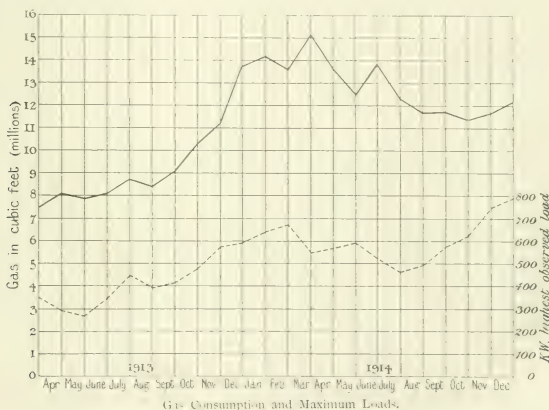
Attention may be called to the curve showing gas consumption, where it will be noted that during March

The present consumption is approximately 39 cubic ft. per kw.-hour.

The wearing quality of the engines is particularly good, and the repairs needed have been very small. The total cost of repairs, including wages and spare parts used, for 12 months is 0.037d. per unit generated, which cannot be called excessive.

The most tried part of a gas engine of the type under discussion is the exhaust valve, and the material which has been found to be the best for the work is nickel steel. Cast-iron valves, though they do not burn on the face, are apt to break at the neck or collar, and a nickel-steel stem with a cast-iron head attached usually gives trouble by distortion and through causing pre-ignition. The valves in the plant referred to have been in operation for over two years without a single failure through breakage.

With regard to the ignition, the low-tension magneto and



1914, a maximum of 15 million cubic feet was used during the month. Up to that date the author had been unable, through pressure of other work, to pay the necessary attention to the question of gas consumption. Then, however, the matter was taken up, in conjunction with the chemist, and by regular analyses of the exhaust gases, combined with instructions to the drivers to drive by the pressure gauge, the gas consumption was reduced to 12½ million cubic feet at the end of May. During the next six months the consumption was again reduced, the load during this time remaining approximately at the same value. This goes to prove the important part which exhaust-gas analysis plays in the successful and economical running of these engines. The average of good working results shows:—

Carbon dioxide	...	...	...	0.8 %
Oxygen	...	...	...	2.2 %
Carbon monoxide	...	...	...	Nil

coil transformer are most reliable, and no failure whatever of these parts has occurred. Sparking plugs, on the whole, appear to give very little trouble, the most frequent cause of failure of a plug being the widening of the gap, due to the burning of the points, and (less frequently) short-circuiting due to fouling by oil.

With regard to the four points raised in the early portion of the paper, the first point regarding the uneven turning moment has been disposed of. Turning to the second point raised, viz. the difficulty of starting a gas engine, the following is the author's experience. As previously mentioned, duplicate ignition systems are fitted to allow for easy starting, but not once in a hundred times is the accumulator used for starting. The engines can be got away on the magneto, from cold, in 8 seconds. This has been done many times, and with a good man on the switchboard a machine can be paralleled in 25 seconds. This assumes that two men are available for the operation. With only one man to do the running-up and paralleling,

one minute would very easily suffice. With such results it surely cannot be said that the modern gas engine is difficult to start.

The third point mentioned on page 646 was unreliability. The plant now described has no stand-by for 10½ hours out of the 24, and during that 10½ hours is run up to, or very little below, its full capacity. These conditions have prevailed for the past 12 months without one involuntary stop.

Finally, as to the cost of maintenance; during the 12 months ended 30 June, 1915, 3,378.440 units were generated at an average cost of 0.132d. per unit. The capital cost of the plant was £12,247, and it had been in operation two years at the commencement of July 1914. The costs include all charges except interest on capital, depreciation, and gas used. The items are as follows:—

Management (portion allocated to power house) ... ..	0.000d.
Drivers' wages ... ..	0.031d.
Cleaners' wages ... ..	0.023d.
Oil, water, waste, etc. ... ..	0.022d.
Sundry stores... ..	0.002d.
Repairs, including labour ... ..	0.037d.
Purifiers, including labour and oxide ... ..	0.008d.
	0.132d.

The power-house staff consists of 9 men: a foreman driver, four drivers, and four cleaners. The shifts are of 8 hours' duration.

A vital question in the running of this type of plant is lubrication. The temperature of the cylinder walls of a gas engine has a great bearing on the viscosity and destruction point of the oil used, and more especially is this true of an engine operating on coke-oven gas. As far as possible the lightest oil should be selected, since it must be accepted as a fact that the lighter the oil the less the carbon deposit will be. Also, a thin oil absorbs a minimum amount of power.

Carbon deposit is one of the greatest troubles of the user of the internal-combustion engine. This trouble is often—in a very "off-hand" way—put down to a bad oil. This is not always so, and it will often be found that carbon deposit is formed, although the oil used may be of the

finest quality and quite suitable for its work, by the driver being too liberal with the amount regulated to each cylinder feed. Bad mixture will of course also account for carbon deposit, and the oil is blamed, when, if an examination of the waste gases were made, the fault would be found to lie, with the driver or charge-man.

A well-known maker of gas engines recommends 1 drop per minute per inch of cylinder diameter. The plant under discussion is run at 1 drop per minute per 3 in. of cylinder diameter. During a continuous run of one week with an average load of 280 kw. the oil consumption for the whole of the engine, including crank-case make-up, was 12½ gallons.

If it were possible it would be undoubtedly preferable to use the same quality of oil over the whole of the lubricating system of the engine; but to obtain the best results this course cannot be pursued. A thin oil, giving excellent results on the cylinders, might cause serious trouble if used in the crank-case. The use of too great an amount of filtered oil at the crank-case is not to be recommended, as no matter how efficient the filter, a certain amount of carbon dust is always left in suspension. Certainly no waste oil should be used with less than three filtrations, and then only as a make-up to the whole body of oil in the crank-case, and never on the cylinders direct. A good crank-case oil has been found to remain in good condition for 12 months before requiring removal. The amount of the oil in the crank-case is about 90 gallons, and about 50 per cent of this is recovered in sufficiently good condition after filtration to use as a make-up oil for the crank-case. It is advisable to make a test of the crank-case oil at least once in six months to determine its condition.

Carbon deposit on the inside is almost as troublesome as carbon on the combustion side of the piston. This trouble can only be reduced by striking the happy medium between the thin and the heavy oils.

The average compression of the engines is about 105 lb. per sq. in., but they have been run with it as high as 120 lb., though at this compression very skilful driving was necessary to prevent pre-ignition. It is usual to find that the compression increases as the engine runs in. An engine put to work at 100-lb. compression will, if kept in good order, go up to 105 lb. or 108 lb. at the end of 12 months running.

## DISCUSSION.

Mr. Selvey. Mr. W. M. SELVEY: Some time ago I visited many of the principal gas-engine installations in this country and came to the conclusion that three things were necessary to make a gas power scheme as reliable as a steam power scheme. These were the right engine, the right fuel, and last but not least the right men. In the early days of large gas engines the most important lack was that of the right engine. When this was overcome, heavy wear and tear caused great attention to be paid to the right fuel. I presume that we are gradually obtaining the right sort of men, but it seems to me to be very significant that the installation described by the author, which is one of the most successful of its kind in the country, though not one of the largest, should be operated by an engineer who has been trained in a steam station. I believe the operating

engineers of steam power stations have taught the engineering world many things by their methods of anticipating difficulties and keeping accurate records. As regards the engine, the makers have so far very wisely limited themselves to a cylinder diameter which is the largest practicable for a single-acting non-water-cooled piston, and although this results in an engine of only about 1,000 kw., there is no doubt that for a concentrated load—such as England as a whole appears to be to American engineers—this size will go a very long way in meeting the somewhat isolated cases where gas engines can be usefully employed. These cases are very largely where coke-oven gas is available outside the area of a large public electric supply company, and alternatively where the plant must be a small producer system. The efficiency of the latest type of this

Mr. Selvey.

Selvey. engine is exceedingly high, as I found in a test on the 29th November, 1914, from which I extract the following results:—

Load and b.h.p.	Heat consumed	Thermal Efficiency, per cent
	b.h.p. per h.p. indicated (calorie value of gas)	
Full load (609.3)	8,130	31.3
$\frac{3}{4}$ load (459.7)	9,225	27.6
$\frac{1}{2}$ load (305)	10,800	23.5
Overload (668.5)	8,320	30.6

Taking my second point as regards the fuel, I am quite satisfied that the author's success is considerably enhanced by the thorough purification of the gas from the ovens. Successful small gas-engine practice was built up on the use of town gas, and it is only to-day that we realize the debt which the gas engine owes to gas engineers in this direction. In a case in which I have been interested I found that violent pre-ignition was accompanied by very high sulphuretted-hydrogen contents in the gas. I searched contemporary records as regards the explosibility of sulphuretted hydrogen, but could find nothing. I wrote to Dr. W. M. Thornton and he knew of no experiments which would tend to show that the presence of sulphuretted hydrogen would make an explosive mixture more explosive. I have therefore been waiting for some time for confirmation as to whether this is so. I think the author has made it reasonably certain. It is very curious that his bog ore purifiers appear to remove tar as well as sulphuretted hydrogen. Pre-ignition has often been attributed to "tar fog" causing deposits in the cylinder, but I have found pre-ignition to be violent where although "tar fog" was undoubtedly present the deposit in the cylinder was quite wet and oily. I think it would be a very good thing if it could be agreed that no designer should contemplate running an engine on coke-oven gas, even if the latter were free from tar, without purification from sulphur. This does not entirely apply to producer gas, which gives trouble owing to its carrying over tar of a very poor nature, while the sulphur contents are very much diluted. Finally, as regards my third point, I think gas engines have often been tended by such men as usually look after colliery pumps, Lancashire boilers, fans, etc., *i.e.* from a modern power station point of view by practically non-skilled operators. The responsible engineer in such cases with his manifold duties other than the production of power requires a plant to run without attention. The author has shown us how repairs and maintenance can be kept low if attention is given before trouble occurs. We can hardly imagine having to open up turbines for examination and cleaning every week-end. If it were once found necessary the power station engineer would see that it was done until some kind of plant was devised which did not require such attention. The author, however, does not wait for his valves to get dirty or his cylinders to get scored. I think there is no doubt that many other engines if they had received such attention would have given more encouragement to their purchasers than they have done.

Mr. W. E. WOODHOUSE: I have seen the installation that the author describes, and I believe the very low repair charges are due to the very careful and skilful supervision which is exercised in its management. The author says that the regenerative oven produces a larger

quantity of gas than the waste-heat oven; to this I agree, but if the surplus heat from coke ovens is to be used for the production of steam there is no doubt that the waste-heat oven will give the bigger surplus. The advantages of the regenerative oven in other directions are, however, so considerable that the present-day tendency is altogether in favour of their use. The author's claim that by using surplus heat from ovens in gas engines it is possible to develop three to four times the power that could be obtained from the use of waste heat under boilers, is a serious over-statement of the case, and one to which I cannot agree. It must be borne in mind that the initial or no-load consumption of a gas engine is some 30 to 40 per cent of the full-load consumption, whereas that of a steam turbine is from 10 to 20 per cent. This being so, the relative consumption on commercial loads with load factors of between 25 and 50 per cent is increased, over that required at full load, much more in the case of the gas engine than in the case of the steam turbine. The author states that many engineers remain unconvinced that the large gas engine has proved to be economical and reliable in service. Though far from being an opponent of the gas engine, I must number myself amongst those engineers. The engines that the author deals with are, of course, not large gas engines. Sets of that size could not be economically used in large power stations. To the objections to gas engines which he mentions I would add two more: the first, the high capital cost of the plant; and the second, the high initial fuel consumption and relative inefficiency at light loads. In reading the paper it appears that there are a number of motors driving auxiliary machinery necessary for the gas-engine plant; for example, that driving the compressor, the cooling-tower pump motor, and the exhaustor. The power required for these purposes is internal to the generating plant, and in making a statement of costs I think the author should have deducted the consumption of those auxiliaries from the total output. The addition of capital charges will, of course, considerably increase the figure stated. I note that the author is using a very small proportion of the total gas from the coke ovens. If his generating station were linked up to a power-supply system such as we have in Yorkshire, the whole of the gas could be utilized for the production of electricity, and benefit would accrue to the colliery owner in finding a market for the surplus, and to the power company in obtaining a source of cheap fuel. The future utilization of our fuel resources is a matter of vital importance to the country, and one in which the public supply of electricity must take a large and important part.

Mr. W. E. BURNAND: There is no doubt that a lot of trouble which has occurred in the past with gas engines has been due not only to lack of attention, but often to too much attention of an unskilled or unsuitable character, and I think few will dispute that under unfavourable conditions trouble is more likely to be prompt and serious with gas engines than with, say, steam plant. The author's experience shows conclusively that trouble is not necessarily an accompaniment of a gas engine. The machines in question, however, can hardly be called large gas engines, since the use of eight cylinders to produce 500 h.p. represents a power-producing unit of only  $62\frac{1}{2}$  h.p., so that many conditions which have occurred with really large sets are

Mr. Woodhouse

Mr. Burnand

Mr.  
Burnside;

avoided in these machines. With large cylinders most troubles are traceable to the piston head and combustion-chamber walls receiving many more heat units per square inch of surface than in the case of a small cylinder. The temperature of the ignited gases being substantially the same in a large cylinder as in a small one, it was natural to assume when the larger sizes were first developed that the metal in contact with the ignited gases would receive about the same amount of heat per square inch as in smaller cylinders. When, however, these large cylinders were put to work it was found that the surfaces received very much more heat than in the smaller sizes, thus showing conclusively that a great deal of the heat which had to be conducted away by the cylinder and combustion-chamber walls was due to radiation from the body of the gas. The magnitude of this radiant energy had never been previously suspected, and it has caused endless trouble in large engines owing to overheating and distortion; but, now that it is recognized, means will no doubt be developed for dealing with it. Two possible ways of doing so I mentioned in the discussion on Mr. Sparks' paper\* last year, the first being to get as near as possible to flameless non-radiant combustion of the gases inside the cylinders, either by perfect mixture of the air and gas before ignition or by a modification of the gas giving a less radiant flame; and secondly by creating inside the cylinder and preferably adjacent to the wall of the combustion chamber a sort of fog impervious to the radiant energy, thus preventing this energy reaching the cylinder walls and confining it mainly to the body of the ignited gases. Possibly a combination of these would give the best results. In connection with this, the improvement mentioned at the bottom of page 648 as the result of a more perfect admixture of air and gas before reaching the cylinders, may be due to the ignition of the flame being more of the character of a bunsen flame, where the gases are thoroughly mixed before ignition, as compared with the sort of flame which occurs with the ordinary flat burner where there is not this previous thorough mixture. In the latter case, as is well known, there is considerable radiant heat, which does not occur with the bunsen flame although there is the same total amount of heat developed in each case. This of course would tend to produce cool and more efficient running, in addition to the better effect mentioned due to the more even distribution of air and gas between the cylinders. I should like to ask the author whether he has tried oxygen for the removal of the carbon deposit mentioned in the paper. This appears to be satisfactory in small motor-car engines, and it would be of interest to know if any unlooked-for effect occurred when used on a larger scale.

Mr. Cooper.

Mr. G. S. COOPER: It seems to me that much of the success which the author has obtained is due to the close co-operation which there has been between the engineer and the chemist, and I venture to say that if this co-operation were extended, very beneficial results would accrue. Mr. Woodhouse has taken up the point of view that a steam plant offers more advantages than a gas-engine plant, and he also advocates that where steam is employed, waste-heat ovens should be installed. I disagree with this entirely from the point of view of the amount of power which could be obtained, but more particularly from the point of view of manipulation of

the ovens. Mr. Selvey has referred to the composition of the coke-oven gas which the author uses, and considers it to be of a better quality than ordinary town gas. I should like to point out that there is no reason why coke-oven gas should not be better than town gas. There is a general impression that coke-oven gas is a very inferior product, whereas I would undertake to produce and maintain a supply of gas of a composition approximately similar to that at Grassmoor. It is very interesting to note the improvement which has been brought about by carefully analysing the exhaust gas, and I should like to ask the author if he has considered the advisability of installing a CO recorder for that gas. I should also like to know whether he has noticed any deleterious effect through the presence of carbon bi-sulphide in the gas.

Mr.  
Simpson

Mr. S. SIMPSON: The total surplus gas from the ovens I make out to be approximately 2 million cubic feet per day of 24 hours, and of this it appears that the plant at present is using at the rate of 1 million cubic feet per day at times of maximum load; in other words, there is still a surplus of 50 per cent, which by co-operation with the electricity supply authorities would have a definite market value and could be entirely utilized if local conditions permitted. The author on page 649 states that the present gas consumption is 39 cubic feet per kw.-hour. This, I gather, is at times of maximum load and appears to differ considerably from previously published results, the consumption during 1913-14 apparently being 53.5 cubic feet per kw.-hour. The calorific value stated on page 648 is, I understand, the gross value, so that the net value will be some 10 per cent less, which agrees with the analysis given. The load on the plant has been increasing and the performances for the past year may be considerably better than this, but the fact remains that such low consumption figures are dependent entirely upon full-load conditions, which are not realized continuously in actual working. Will the author please state: (1) Whether the capital cost of £12,247 covers everything from the purifiers to the switchboard, *i.e.* includes buildings and foundations, etc. (2) What proportion of capital cost is represented by the purifying plant?

(Communicated): In dealing with the working results it is a pity that the author has not completed the particulars as to the actual consumption obtained under working conditions, by including in the diagram on page 648 the number of units generated. From previous particulars of this plant\* I gather that, in 1914, 2,886 million units were generated from 1544 million cubic feet of gas. In the absence of any statement as to the annual power consumption of the various auxiliaries required on the station plant, and allowing 5 per cent for this item, we get 274 million units net production at a consumption of 50.5 cubic feet of gas per unit, which at 480 B.Th.U. (lower value) per cubic foot represents 27,120 B.Th.U. per unit, or 12.6 per cent thermal efficiency on a station load factor (based on the highest observed kilowatt load sustained for half an hour) of 40 per cent. This is about the average for colliery installations, unless special arrangements are made such as for night or week-end pumping, etc. The above figure of 50.5 cubic feet of gas per unit differs considerably from the author's statement on page 649 that "the present con-

\* *Journal I.E.E.*, vol. 53, p. 653, 1915.\* *Iron and Coal Trades Review*, vol. 91, p. 12, 1915.

sumption is approximately 30 cubic feet per kw.-hour," and I take it that here he referred to the gross kw.-hours generated at maximum load; in which case the commercial result over a working period of a month or a year is quite another matter. It has been emphasized during the discussion that there is a vast difference between consumption figures at full load and at the average working load obtaining over, say, a year of ordinary working conditions. This important point is by no means generally realized by people when considering, say, the economical production of electrical power from coke-oven gas and the relative merits of gas engines versus gas-fired boilers and steam-turbine plants. I estimate the surplus gas available from the ovens to be approximately 2 million cubic feet per day of 24 hours, of which the gas-engine plant, even at times of maximum load, will not use more than at the rate of approximately 1 million cubic feet per 24 hours, or 50 per cent of the rate of normal surplus production. The desirability of co-operation of such colliery coke-oven installations wherever possible with gas or electrical undertakings, to utilize the surplus gas at present wasted in so many cases, was referred to in the discussion, but is, I think, particularly emphasized by Fig. A herewith, showing the average monthly rate at which gas was wasted in 1913 and 1914 on the particular plant under discussion. I have taken the author's diagram of gas consumption for the months during 1913-14 and inverted it, from which it will be noted that the colliery company's use of the gas for their own power requirements only amounted to 20 per cent of the total surplus available, the remaining 80 per cent being wasted. This problem of the utilization of waste gases, etc., is becoming of national importance, and is one of the many directions in which we shall have completely to organize on a national basis if British industries as a whole are to compete successfully with those of other nations. Cheap power is of vital importance to industrial developments, and co-operation of this type is one of the means to that end. The present shortage of coal deliveries emphasizes the fact that the demand for coal in this country is in excess of the supply, and any economies in coal consumption by co-operation in the use of waste gases will also set free considerable quantities of coal for present industrial needs and future developments. The transmission of the waste gases to local gas undertakings is already being carried out in a few cases, but in the majority of the installations the local conditions will not permit this, and undoubtedly here the public electricity supply undertakings must, in the near future, play a large part in the distribution of electrical energy from the coking plants to the individual user, industrial or domestic; the electrical service connection to the colliery providing at the same time a stand-by supply, and thereby greater security for a uniform coal output. The developments in the North-East coast area during the past few years are a practical example. In the United Kingdom during 1914 some 12 million tons of coke were produced in coke ovens, and if these were all of the by-product recovery type (which will sooner or later be, I think, a statutory requirement), the surplus gas available for power production would, I estimate, yield 1,000 million units per annum, or a steady output of 115,000 kw. Further, considering blast furnaces, 892 million tons of pig-iron were produced during the year, and the surplus gas available for power production

would, I estimate, yield 1,785 million units per annum, or a steady output of 200,000 kw. These two economies would, I think, supply, for example, at least 50 per cent of the total colliery power requirements of the country, and in view of the fact that 6 to 8 per cent of the coal tonnage output is used by collieries for their own requirements, some 9 to 10 million tons of coal per annum would thus be saved and set free for other industrial requirements and developments if a properly co-ordinated scheme were organized by co-operation with the electricity supply undertakings on a national basis for the various areas. With regard to the working costs given by the author (page 650) the corresponding number of cubic feet of gas used for the year ended 30 June, 1915, should be stated, and I venture to submit the following amendments to the statement of the total generation costs:—

3,378,440 units generated, and say 3,210,000 units to the colliery circuits.

Item	Pence per unit (gross generated)	Pence per unit (net, i.e., to the colliery)
Management, wages, oil, waste, water, stores, repairs, and purifiers ... ..	0'132	0'139
Interest at 5 % and depreciation at 7½ % on £12,247 ...	0'109	0'115
Gas, 165 million cub. ft. at 3d. per 1,000 cub. ft. ... ..	0'147	0'155
Total, with no spare plant ...	0'388	0'409
Interest and depreciation for 4th set (spare), say 12½ % of £4,000 ... ..	0'035	0'037
Total costs ... ..	0'423	0'446

It should be noted that the present light repairs cost of £520 per annum, or 0'037d. per unit generated, is likely in the course of the next few years to increase fairly considerably, since each set at present averages 20 hours' daily running time. In other words, one year is really equivalent to two years' ordinary wear and tear, and this often tells in subsequent years. The above results are undoubtedly very good and may be taken as obtaining under the very best joint circumstances of excellent engine design and workmanship, well-arranged plant lay-out, and careful attention to purification of gas, excellent management and supervision as to running, such as correct adjustment of the gas and air, and attention to maintenance requirements ahead of trouble. I am sure, however, that the author would find many supply authorities who would have been only too glad, if they were within reach of him, to take on this colliery load at, say, 110 per cent of his cost per unit. Were this possible, it would certainly have paid the colliery company and saved them a capital outlay of £12,000 on what is (so far as they are concerned) unproductive plant. This would have paid for 12 additional regenerative coke ovens, with the result that a corresponding increase in the profits would be obtained from the coking and by-products owing to the improved efficiency of working and increased yields from the larger installation. At the same time, the supply authority would have been a most likely customer for all the surplus gas, including the 18 per cent increase, and of course the greater

Mr.  
Simpson.

Mr.  
Simpson.

the amount available at any one point, the better the commercial proposition for capital outlay on generating plant. The colliery company in a case like this would have had the additional advantage of two sources of electricity supply, one direct and the other from the supply company's mains. This brings me to my final point, namely, that the most economical means for the production of electrical power from coke-oven gas must depend upon the party with whom the choice lies. If with the colliery company, then for a relatively small installation where sets not exceeding 300 kw. each can be conveniently used as in the present case, gas engines will show probably 20 per cent better economy over the year's working, though capital and repair charges will be higher. If the plant is isolated, and some surplus gas in excess of possible re-

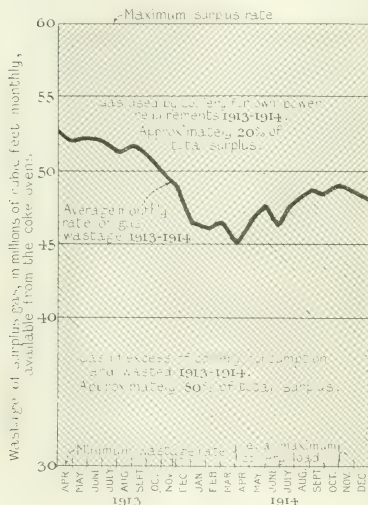


FIG. A.

quirements going to waste, then fuel economy is not worth paying for at the moment. On the other hand, supposing the choice of plant to lie with the supply authority, three points arise: (1) capital cost, (2) economy of operation, (3) reliability and stand-by fuel. On the grounds of (1) and (3) there is, I think, no question that for 1,500 kw. capacity and over, the gas-fired boiler in conjunction with a steam turbo-generator installation is the soundest commercial practice, and as regards economy of operation it is now possible with the improved efficiency of gas-fired boilers and turbine plants to obtain consumption efficiencies under working conditions practically equal to the gas-engine performance. The difference is certainly not worth the extra capital and repairs charges. The units of

plant can be larger and will of necessity be larger as the coking plants become more centralized for reasons of economical carbonization. Further, provision can in this case also be made for coal firing as a stand-by when the gas supply is interrupted or deficient, owing to repairs to ovens or other causes affecting the coking and by-product plant operation. This latter aspect is, I think, of first importance to the public supply authority in view of their obligations to give a continuous and reliable supply.

Mr. G. DEARLE (*in reply*): I am quite in agreement with Mr. Cooper that on a plant of this kind the engineer and the chemist must pull together, and that the results are thereby greatly improved. It is regrettable that in the majority of cases the chemist is ignored where engineering matters are concerned at a colliery. With reference to the analysis of the exhaust gas, a CO<sub>2</sub> recorder would be useful, but what is actually required is a CO recorder, which would give a continuous chart, and should be an instrument in as simple a form as possible. I doubt whether there is such an instrument on the market to-day. The amount of carbon bi-sulphide in coke-oven gas, as compared with town gas, is an absolutely negligible quantity, and gives no trouble whatever.

There is no doubt that sulphuretted hydrogen is mainly responsible for pre-ignition, which is mentioned by Mr. Selvey. The design of the combustion chamber and the shape of the piston crown have an undoubted bearing on the point, but it has been my experience that where an engine will run perfectly well and free from the slightest trace of pre-ignition with clean purifier boxes, pre-ignition at once commences when the boxes become foul, and the sulphur content of the gas rises.

Mr. Woodhouse states that the no-load consumption of a gas engine is some 30 to 40 per cent of the full-load consumption. I cannot agree with this figure, and from recent tests should say that 15 to 20 per cent is more correct for a well-designed engine. I think, too, that the steam turbines which Mr. Woodhouse has in mind in his comparisons are probably sets of 1,000 to 2,000 kw. If the performance of a 350-kw. turbine were compared with that of the engines referred to in the paper, I do not think the turbine would have the advantage by nearly the figure that Mr. Woodhouse quotes. He also states that the engines "are, of course, not large gas engines." This may be true in comparison with some of the large horizontal engines installed in Germany, but for this country they are large sets, and I am convinced that it is along the lines of the multi-cylinder engine of this type that we must look for the development of the gas engine. Mr. Woodhouse also mentions that I am using only a very small proportion of the total output of the ovens. As I do not state what the total output from our coke-ovens is, I fear he must have based this statement on somewhat hypothetical grounds. I will deal with this point later in my reply to Mr. Simpson.

With regard to the removal of the carbon deposit mentioned by Mr. Burnand, in the engines in question this does not occur where it could be treated by the oxygen process. The piston crowns and valve pockets are perfectly clear of carbon, but it occurs at the back of the piston rings, on the under side of the pistons, and on the top of the middle head, and therefore the process named cannot be used for its removal.

Mr.  
Simpson.

The total surplus gas assumed by Mr. Simpson is very largely in excess of what is actually the case. It would appear that he has assumed the whole of the 110 ovens to be constantly at work on full output, a condition which never occurs on any coking plant; and he has also assumed that the ovens are working quite up to the maker's guarantee. The gas consumption of 39 cubic ft. per kw.-hour was recorded on an actual test over a considerable period, and is not based on a period or periods of maximum load. I would point out that the load on the station has very considerably increased since the results published in the *Iron and Coal Trades Review*. I would also point out that the colliery is using gas for other purposes than the supply to the power house, and this, coupled with the fact that Mr. Simpson's assumed surplus figure is too large, makes the diagram accompanying his remarks of no value for the purpose he would have it show. In reply to Mr. Simpson's two queries, the figure of £12,247 covers the whole of the plant, the cost of the purifiers amounting to

approximately one-tenth of this sum. With reference to costs, I stated in reading the paper that with the addition of capital charges the total cost was 0.404d. per unit generated; this figure is approximately the one Mr. Simpson arrives at in his amended costs, less the 12½ per cent interest and depreciation he allows on a fourth set. With regard to the 110 per cent of the production cost mentioned as the figure at which supply companies would have been willing and eager to have taken on the load of the station dealt with in the paper, it would be interesting to know how many miles of duplicate line Mr. Simpson would have been willing to run to obtain the load, the approximate cost of such a line being £500 per mile, and also what guarantee of units consumed he would have required at the price of production mentioned above before he took on the supply. With regard to the other points raised by Mr. Simpson, I fear that they are outside the scope of the paper, which deals with a plant entirely isolated from all electric supply companies' areas.

## DISCUSSION ON

### "ELECTRIC HEATING: ITS PRESENT POSITION AND FUTURE DEVELOPMENT."\*

YORKSHIRE LOCAL SECTION, 12 APRIL, 1916.

Mr. E. C. WALLIS: Some years ago I was called to a house in the neighbourhood of Leeds where gas apparatus had been installed. The air from outside of the house was brought in through a conduit, passed through a small iron chamber heated by a gas stove, and then into a bedroom which had to be maintained at an even temperature. With the gas heater the products of combustion got into the room, and the apparatus was accordingly unsatisfactory. I endeavoured to supply something that would give better results; I succeeded fairly well and was able to keep the room at an even temperature throughout the night, but with the author's apparatus I could have done it in a more effective way.

Mr. E. DENTON: I should like to ask the author whether mercury has any deteriorating effect on the steel tube, and if so whether the tube is treated in any way before being used.

Mr. T. ROLES: The author states that "there is probably no branch of electricity supply in a more flourishing condition to-day, or receiving greater attention from both electrical engineers and the public, than that of electric heating as applied to dwelling-houses and business premises." Twelve months ago I should have been inclined to agree with him; but most of us are now so busy on work entailed in the giving of large power supplies to firms engaged on munitions work that the question of electric heating has not received during the past year the attention which it was receiving up to then. There is still a great demand by the public for electric heaters, but

we are finding it very difficult to meet the demand and also, owing to the increase in the cost of coal, to keep the price of current down to a reasonable figure. We must remember, however, that the cost of coal to the public has also risen, and this is generally to our advantage. I quite agree with the author that the small radiator of the radiant-heat type, which was practically the only effective electric heater some eight or ten years ago, was largely responsible for the bad name that electric heaters then obtained. This was not so much the fault of the radiator, which was of a very efficient type, as the high charges for energy, which resulted in radiators of too small capacity being installed. Now-a-days, of course, we have radiators taking up to 4 kw., and by many undertakings the smallest size recommended is about 3 kw. Regarding rating, I have usually worked on the basis of at least 1 watt per cubic foot of space to be heated, and for ordinary purposes this is usually found satisfactory. In advising 1½ watts the author is certainly on the safe side, except in the case of very draughty apartments. The author states that with electric heating there is no vitiation of the atmosphere and a room does not get stuffy. I agree there is no vitiation, but at the same time I think we must admit that at times a room so heated does get stuffy. I mention this because we should all recognize that where electric radiators are used the tendency is to keep the windows shut. People are too lazy to open the windows, or are anxious to avoid draughts, or want to raise the temperature as quickly as possible, or desire to save current. If electricity is supplied at a cheap rate

\* Paper by Mr. G. Williamson (see page 200).

Mr. Roles.

the sizes of the radiators used can be such as to allow of rooms being efficiently ventilated, and no complaints of stuffiness will then be received. I fully agree with another point which the author has made, namely, "it is essential to complete success that automatic temperature regulation should not be obtained at the expense of cheerfulness." That is a great difficulty which has to be contended with when radiators of the bar type are used, and I do not see that we can easily get over it. In radiators of the Dowling type this disadvantage is not so apparent, as when alternate lamps are switched off and the lamps are not badly blackened, the appearance of the radiator is but little different from when all the lamps are in use. In radiators of the bar type the elements are usually switched in adjacent pairs, so that the switching out of one section detracts considerably from the cheerful appearance of the fire. Matters might be improved if alternate, instead of adjacent, elements were switched together, as a large unbroken surface of cold white fire bars looks anything but cheerful. In certain types of fires the difficulty is to some extent surmounted by a coloured lamp being placed in a suitable position behind the bars. In my opinion for a considerable time to come the greatest use will be made of electric radiators during spring and autumn. In winter, especially in the northern counties, one needs either good fires or central heating by means of hot water, but in spring and autumn it is unnecessary to keep fires or heating apparatus going all day, and an electric radiator is the ideal medium for supplying what heat is required during the evenings. Even in summer, on chilly and dismal days, a room looks anything but cheerful without a fire, and in this part of the country one often finds a fire used on summer evenings. An electric radiator of cheerful appearance but of small heating capacity would prove far more convenient and economical than a fire for use on such occasions. The author's device has proved fairly successful at Bradford, the chief trouble being that the contacts have become dirty, the apparatus then failing to act. The device has also been found to be more sluggish in its action than I consider desirable. It must be taken into account that by far the greater proportion of electric heaters which are likely to be used in connection with such thermostats will be of the radiant pattern. Such being the case, even if the temperature of the apartment is kept practically constant, a feeling of chilliness will be experienced by the occupants immediately the fire is switched off by the action of the device. This can, of course, to some extent be obviated by arranging for the thermostat to control a section of the heater only. The apparatus should, however, have quite a large field of usefulness, especially where it is necessary to obtain close regulation in the temperatures of apartments. For the present, at any rate, I do not contemplate that it will be adopted to any considerable extent for the purpose of effecting economy in the consumption of electricity. Those who are at the present time adopting electric heating do not trouble so much about the cost, but install electric fires chiefly by reason of their convenience. On the heating of houses rated at £25 and under being seriously tackled, the question of economy will become considerably more important. We shall, however, have to wait until after the war before any great

progress is made in connection with the heating of small Mr. Roles premises.

Mr. E. BALMFORD: Looking at the paper from the domestic side, sufficient attention does not appear to have been given to the question of cheerfulness. In many households, even when a room is well heated, the fire is kept burning in order to give a cheerful and homely appearance to the room, and the average Britisher, especially among the working classes, will suffer a considerable amount of inconvenience rather than do without a fire, and it will take a considerable time to educate him to do otherwise. When electric heating by means of convectors was first introduced, even the most enthusiastic amongst us could hardly call them cheerful, and the comparatively low temperature at which they worked allowed anyone to sit on them for a considerable period without suffering any great discomfort; this gave the householder the impression that they were of little use, and so set up a prejudice against electric heating. When an attempt was made to remedy this by means of lamp radiators, a 4-lamp (1 kw.) radiator was in many cases used to replace a 1½-kw. or 2-kw. convector, with of course worse results than before, as the rating, in many cases already on the low side, was reduced lower still. Now that the hot-bar type of fire has attained some degree of perfection and electric heating is coming into its own, its progress is very much hampered by this early prejudice, and unless the matter is very carefully handled its progress may yet be retarded. Take the case of a room, say, 14 ft. by 14 ft. by 10 ft., such as is likely to be met with in a house rated at from £20 to £25 per annum. A 3-kw. radiant fire would probably be installed, and even when this is at full heat it forms but a poor substitute for a good coal fire from the point of view of cheerfulness. If now, say, four bars of the radiator are thermostatically controlled, when these are switched off the loss of radiant heat at once causes the room to feel chilly, as the author points out; the now non-luminous bars add to this effect, as the appearance of a radiator with two-thirds of its radiating surface dead is anything but cheerful, and I am afraid that this would revive the old prejudice, especially among the ladies—and in most households it is the woman that has the say in these matters. With regard to the rating, in connection with some work in which I was interested the problem arose as to what method of heating should be employed in some temporary stores which were being erected. They were built of single ¾-in. weather boarding and the roof was covered with tarred felt, sufficient window space being provided to give fairly good lighting. Electric heating by means of convectors was finally decided upon, as against an external coke boiler, on account of its easier control, more even temperature, cleanliness, and less fire risk. The capacity of the building was 11,000 cubic feet and six 2½-kw. convectors were installed, giving a rating of 135 watts per cubic foot when full on, and these were controlled by one main 3-heat switch. It was found, however, that if the heaters were kept on second heat (9 kw.) day and night a temperature of 55° to 60° F. was maintained with a temperature of 30° F. outside but very little wind, thus leaving a fair margin for exceptionally bad days. It was of importance to maintain a fairly even temperature in order to prevent the material in the stores sweating and so causing deterioration.

Mr. Balford

Mr. R. H. CAMPION: When I read the paper I thought what an excellent device the author's would be for railway carriages if it were not for the cost. From the central station point of view it also occurred to me that if a consumer installed this apparatus he might leave his radiator in operation throughout the night as he would probably forget to use the controlling switch unless it were connected up with the radiator. I should like to know whether, when the radiator is switched off, the thermostat is also disconnected from the supply. With regard to mercury contacts, I know that there is chemical action whereby the mercury is cleaned, but after 10,000 interruptions would not the mercury become dirty and have to be renewed? I think that needs careful investigation. Another point is that if a large radiator were replaced by two or three smaller ones a better effect would be obtained. Will the author state in his reply: (1) what is the approximate cost of the apparatus; (2) whether one circuit breaker will control four radiators in four different rooms in a house or whether a thermostat will be required in each room; (3) what are the limits of the scale?

Mr. W. LANG: I think there is a great deal of misapprehension with regard to luminous effect. I have always held the opinion that this effect is more artificial and imaginary than would be the case if one experienced comfort in a room, even though there were no fire there. My experience in the United States was that at first I looked for a fire in winter time, but I think this was mostly due to habit, because if I was not very long in the room and it was at a moderately comfortable temperature I thought no more of the fire. I am convinced from this that if we had radiators giving satisfactory heat in a room people would never maintain that they were comfortable only with a blazing, brilliant fire. Why I mention this, is that I think it may be a mistake for manufacturers to provide a luminous heater if they are not convinced that this is the proper method of heating a room. One of the weaknesses of the author's apparatus is, I understand, that it must be employed in the room in which the radiator is in use; whereas an American apparatus is provided for central use, that is, to control two or three radiators in different parts of the same house. If that be the case would it not be possible to aim at a better method of heating houses electrically on the principle of the central heating employed in American houses? If such an effect were obtained there would be a diversity factor owing to the different conditions in regard to heat in various parts of the house, the radiator thereby being kept in continuous use. One common fault in connection with electric heating is lack of ventilation. The same result occurred when electric light was first used on a large scale in buildings. This was principally due to a gas corona having previously been fixed in most large buildings close to the ceiling under a ventilating duct, so that, when the gas was burning, the current of air passing out of the building formed a natural draught. With electric heating the same trouble has arisen, and it occurs to me that if we could initiate a form of central heating whereby hot air would be delivered to the rooms we should have hot, dry, fresh air naturally displacing the vitiated air in the rooms. These are lines along which perhaps it might be best to follow in the future.

Mr. W. HARTNELL: For warming a room hot air is uncomfortable unless it has heated the walls and furniture before the room is occupied. A room feels most comfortable when the air to be breathed is cool but the walls and surrounding objects are pleasantly warm. Hence, in general, radiant heat such as that from an open fire or electric radiator is much to be preferred to hot air for warming the rooms of a house. Although electrical energy considered as fuel is much more expensive than coal or gas, yet it has so many advantages for heating that it is certain to be largely used. The author's switch will effect economy and increase comfort. Living rooms must be well ventilated. There is need for a regenerative system whereby the vitiated air can warm the incoming cool air, which possibly may be drawn in by an electrically-driven fan, the heat from the motor being also utilized.

Mr. W. A. GILLOTT (communicated): Mr. Hughes questioned in the Scottish discussion (page 217) the accuracy of the curves on room heating which I gave in my recent paper.\* I have very carefully compared his statements with the original set of curves I made, which are on a much larger scale than those reproduced in the *Journal*, and I find that his assertions are not justified. There are slight variations due to the fluctuations in the voltage, mentioned in the paper; the fluctuations were between 228 volts and 262 volts. The current curve was plotted from a series of observations taken from an ordinary ammeter, and the energy-consumption curve was recorded by a kilowatt-hour meter continuously in circuit throughout the test. Fluctuations of pressure would consequently cause a slightly uneven curve; this, however, does not alter my claim that it is more economical to use a large heater for a short time than to use a smaller one for a longer period. If Mr. Hughes will again examine the curves, he will see it is proved conclusively to be cheaper to use a large heater for a short period than to use a small one for a longer period. In Fig. 9 at the fifth hour a temperature of 60° F. was obtained with an expenditure of energy of 10.5 units, whereas in Fig. 10 at the fifth hour only 9.5 units had been consumed, although the room had been maintained at approximately 60° F. for 4 hours. It must also be noted that in Fig. 10 the outside temperature was less than in Fig. 9, thereby giving further proof of the economy of large heaters. Mr. Hughes' theories of room heating are not applicable to practical operation. It is, of course, possible to provide a large heater to raise the temperature of a room, but it is impossible to supply a small heater of fixed rating to maintain the desired temperature owing to the variation in the outside temperature. The small heater may be correct when the outside temperature is, say, 40° F., but of no use when it is 35° F., and too large when it is 45° F. Also the temperature of the room will vary according to the aspect of the room and the direction of the wind. His secondary or smaller heater would therefore be of no use to comply with these varying conditions. My impression is that his remarks are from a theoretical point of view, whereas mine are the results of actual tests carried out under ordinary working conditions, which results are the only ones to be taken seriously from a commercial standpoint, and of course this is the point that decides.

Mr. G. WILKINSON (in reply): It would take too long to

\* *Journal I.E.E.*, vol. 53, p. 42, 1915.

Mr.  
Hartnell.

Mr.  
Gillott.

Mr.  
Wilkinson.

Mr.  
Wilkinson.

reply in detail to all the points raised during this discussion. A perusal of the observations made by the various speakers only serves to emphasize the importance of employing powerful apparatus whatever method of heating is used, in order that the apartment may be raised to a comfortable temperature in a short time. Slow heating in the early hours and too high a temperature in the latter part of the day are innate defects of the coal fire. For instance, how frequently do people have to take breakfast during winter in a cold room owing to the fire being black and feeble, and it is long after they have left for business that the room becomes warm. Probably the room is no longer required and thus great waste of fuel takes place for want of effective control. We are entitled to expect a room to be warm when we want it, and this is a convincing argument for high rating. We cannot, however, have a high rating with electric heaters without a heavy bill for electrical energy unless the radiators are controlled automatically by temperature regulators.

In regard to stuffiness, mentioned by Mr. Roles, if we use so low a rating as 1 watt per cubic foot during cold weather, we have no margin left for ventilation; it is better to adopt a higher rating and have adequate and continuous ventilation. One watt per cubic foot is too little; we must have  $1\frac{1}{2}$  watts per cubic foot in the most sheltered room, and more in exposed situations, and then we can have effective ventilation. I never use an electric radiator in a room without having a window open, and I have never found the room get stuffy.

In regard to cheerfulness, if we have, say, a 3-kw. radiator or electric fire in a room and leave two of the 500-watt bars always in operation and also a red lamp continuously burning, we do not suffer from cheerlessness. This is not merely my conclusion but is the opinion of ladies who have had extended experience, and in matters of this nature their conclusions may be taken as absolutely above question.

Mr. Campion advocates the use of several heaters intelligently disposed within the apartment rather than one large heater in a fixed position. I entirely agree with him. As radiators become cheaper it will be far better to have a few smaller ones in different positions

than to have one big one. The chief reason why we employ one of large size only, is that we have a big fireplace and want to put something in it. When fireplaces are relegated to the scrap-heap the number of heating positions will be increased, with correspondingly greater comfort and convenience.

I have been asked if the steel tube is specially treated before being filled with mercury. As steel is unaffected by mercury no treatment is necessary; the tube is, however, left unfinished and the sooner it rusts the better, because it is then probably more sensitive to changes of temperature. I have never found the mercury in the circuit breaker deteriorate beyond a certain point; after a thin oxide has formed on the surface, the remainder appears to be effectively protected and preserved in a clear and mobile condition.

Mr. Lang has referred to his experiences in the United States. An open fire is not required there because it is not the custom to have one, and the same remark applies to the Continent. The craving for the sight of a fire is largely a matter of sentiment, and millions of our fellow creatures in civilized lands live comfortably in well-warmed houses without either seeing fires or desiring to do so.

A pressure of 500 volts is safely dealt with in a switch having less than  $\frac{1}{8}$  in. break. If I had time I would put such a switch to graduated high-tension tests to discover its limitations. I intend to do it at some future time unless a manufacturer takes up the design meanwhile. As far as my information and observation go, there is a successful future before it. I should like to refer to a letter I received this morning from a well-known firm of electrical engineers who state that they have been trying one of my thermostats on a loading of 55 watts, viz. half an ampere at 110 volts, at which excessive loading it ultimately failed due to fusion.

In reply to the point raised by Mr. Hartnell, I think that the whole secret of successful heating is founded upon the following: we are comfortable when heat is being diffused by our bodies at a normal rate only, but when our bodies are parting with heat at an abnormal rate we are always uncomfortable.

## DISCUSSION ON

## "CONTINUOUS-CURRENT RAILWAY MOTORS."

Mr. E. V. PANNELL (*communicated reply*): The point raised by Mr. Carter as to the status of the 1-hour rating I fully appreciate, and indeed have expressly stated in the paper that this rating forms no criterion of the service capacity of the motor, this conclusion being supported by the curves in Fig. 8. In a paper of this kind, however, one is faced with the necessity of having some basis of comparison for different designs, and at present the 1-hour rating is all that we have. It is of course impossible for a rating to indicate just what the motor will do under the many varying conditions of service, nevertheless it is quite time that something more representative than the 1-hour run was introduced. With the present rapid spread of electric railway construction in this country I think the adoption of some standard basis of comparison for railway motors to be well worth the consideration of a committee of the Institution. In respect of the 1-hour rating, the trouble is aggravated by a little conspiracy among the manufacturers to refrain from revealing the nominal rating of their motors, so that different makes are not susceptible of comparison. Thus it is that a 180 (rated) kw. motor is advertised as being of 150 kw. and a 150-kw. motor as being of 120 kw. rated output. The 1-hour rating may not be a good basis of comparison, but at least it represents the performance under certain definite conditions and should therefore be a definite quantity.

Mr. Carter gives us some useful data on the GE 248 motor which is handling the heavy steel Coney Island express trains on the New York Municipal Railway, a service of exceptional severity. My remark, that the full field of this motor was 25 per cent in excess of the normal, referred to the flux at rated load and not to the excitation. The comparison between the older unventilated motors, as typified by the GE 69, and the newer type represented by the GE 248, is very instructive; I would point out, however, that the shortening of the core length necessitated by the introduction of the fan is not all net loss, because in the fan-ventilated motor the radial armature ducts are abandoned. The loss of  $2\frac{1}{2}$  in. due to the adoption of the fan is therefore partly offset by a gain of  $1\frac{1}{2}$  in. to 2 in. from the absence of ducts.

The relation of a 20-in. armature to a 33-in. wheel was of course stated in the paper as a maximum, and I quite agree that this does not leave much for the radial length of pole core, motor-shell, and axle. I believe Mr. Carter will find that the earlier Interborough Subway cars in New York City were equipped with Westinghouse 86a motors having 20-in. armatures and 33-in. wheels; but, as he quite rightly says, the clearances required in this country are greater, particularly on account of the central location of the fourth rail. Turning to the matter of ventilation, I note that the hollow-shaft GE 66 motor was used to a less extent than I had supposed, and the fact that the combination of longitudinal and radial passages did not lend

itself to really effective ventilation quite confirms my own Mr. Pannell. conclusions of this design. Reverting to the sectional drawing in the paper, the criticisms of Mr. Carter and other speakers are quite sound; the diagram was drawn out mainly to show the proportions of the electrical and magnetic circuits, and the mechanical design was not worked out in detail as the tabulated quantities also show.

Referring to the remarks of Dr. S. P. Smith and certain other speakers, I am very glad that the proposed 1,800-volt design has been so ruthlessly criticized, because I started out with the idea of taking a perfectly normal motor carcass and working out the details for 600, 1,200, and 1,800 volts to ascertain as far as possible the limits of practicability. The last mentioned is of course an extreme design and demonstrates that if we want to use this pressure for railway motors we shall be working up against an average voltage per segment of 20 and a segment pitch of about 0.15 in. There is no getting away from these limitations except by increases in the motor dimensions, which would bring it into the locomotive class. On the whole, therefore, one is forced to the conclusion that if continuous-current pressures are raised beyond 1,200 volts they will be beyond the scope of motor-car and in the field of locomotive operation.

Mr. Lydall points out that the limiting feature is the maximum voltage per segment and not the average, a fact which nobody will dispute. Unfortunately there is no way of predetermining the maximum in a preliminary design; all we can do therefore is to adopt an average value, fictitious though it may be, and keep that as low as practicable. Mr. Lydall mentions an average of 18 volts per segment as not being abnormally high; as an additional example might be mentioned the 1,500-volt motors that were running on the Bellinzona-Mesocco tramway some years ago in which the terminal voltage divided by one-fourth the number of segments gave the figure of 22 volts. Again, if the published information is correct, the 120-kw. motors operating on the Moselhütte locomotives have 183 segments and a terminal voltage of 1,000, giving an average of 21 volts between the commutator bars with satisfactory commutation. In view of these instances, therefore, the figure of 20 volts adopted for the 1,800-volt motor is not quite unprecedented. Moreover, field control with any such motor does not mean a dangerous degree of field weakening by any means. The so-called "short-field" characteristic of the motor is a perfectly normal speed curve, whereas the "full field" gives a very flat curve due to the extra high saturation.

In the comparison of two 48-kw. motors to which attention is drawn by Mr. Dover I have rated down the GE 201 to a 500-volt basis so that the speed of this motor is 590 r.p.m. as compared with 550 r.p.m. for the GE 74. The rated output is of course similarly reduced, consequently the GE 201 motor is shown in its most unfavourable light. It is quite true that the recent weight

Mr.  
Pannell

reductions are due in some measure to increase of speed, but it is mainly to the credit of the interpole that these higher speeds are possible with satisfactory commutation. Notwithstanding Mr. Dover's statement that the self-ventilated motor would show up better on the 1-hour run than an unventilated machine, I am inclined to think that ventilation has very little effect on this short stand test, as is shown by Fig. 8 in the paper and confirmed by Mr. Carter's remarks. This test run is more a criterion of the heat absorptive capacity of the motor than of its heat dissipation.

Mr. Ferguson added some valuable comments, particularly in regard to the question of two motors per car versus four. Of course, as Mr. Barnes has stated, in extreme cases requiring over 500 rated kw. per car four motors are unavoidable. I am not prepared altogether to concede that a single ventilated 180-kw. motor will have a lower service capacity than two 90-kw. machines. For one thing the armature of the former will be larger, giving a higher peripheral speed and less restricted ventilating passages; a great deal more depends upon the design of fan and ducts than upon the watts per square inch of surface. My objection to the forced-draught system is that it introduces a further and unnecessary link in the chain, a defect in which would seriously affect the reliability of the service. For locomotive working, however, where the whole of the equipment is under the supervision of two skilled operators this objection would be of little weight. The somewhat greater weight of field-controlled motors as compared with the standard type is unavoidable owing to the greater quantity of field copper necessary to secure the very high saturation for low speeds.

The summary of railway-motor development presented by Mr. Peck is of considerable interest, and, as he states, it has taken a long experimental period before we could double the terminal voltage on this class of machine. However, we now have motors operating at 1,200 volts terminal pressure on the new Manchester-Bury line, whilst 1,500 volts is being applied to the motor terminals on the St. Paul line in the States, and 2,400 volts to the double-armature motors of the Michigan Railway described in Mr. Storer's recent paper.\* The figure of 1,800 volts is therefore not so far beyond the realm of practical politics, although it should be mentioned that this pressure was selected only to afford a comparison with the 600-volt and 1,200-volt proposals.

We are indebted to Mr. Barnes for some of the most interesting details in connection with the new Lancashire and Yorkshire electrification. Of course my assumption for typical service for a railway motor related to an urban subway, but, as Mr. Barnes shows, suburban-railway operation of a more extended nature is at least as severe,

especially where such heavy gradients are encountered as is the case on the Manchester line. However, at the present time one type of railway service is just as severe on the motors as any other type, because equipments are usually run at the maximum output they will deliver consistent with a specified reasonable temperature rise. Where this is not the case the motors are too large for their work and the greatest economy is not realized.

Mr. Roger Smith besides accepting the very onerous duty of reading a paper on behalf of an absentee has added some valuable comments. In the matter of peripheral speeds I must confess to a certain degree of conservatism and would suggest 7,500 ft. per minute as a desirable limit. In certain installations 600-volt motors are running with their original windings on 750 volts, and the choice of a reasonably low speed enables this to be done. In regard to efficiency, it is largely a matter of choice whether we care to have the high copper losses associated with the low-speed motor or the heavy gear and core losses attached to the high-speed machine. As mentioned in the paper this is to a great extent determined by the service. Now in regard to high-speed railway work I am fully in accord with Mr. Smith that to obtain the flexible characteristics necessary we need something more than the ordinary series winding, and most probably the locomotive of the future will be equipped with compound-wound motors. By this means the series coils will afford the high starting torque, and the shunt will afford regulation and regeneration. All this means a large and heavy motor and predicates locomotive operation. Speeds of 60 miles per hour are of course not unknown for motor-car operation, as some of the high-speed interurban lines in the United States attain a speed of about a mile a minute when free running on their own right of way, and in this connection it is interesting to note that with a 2:1 gear ratio the peripheral speed of the armatures is about the same as the speed of the train. High-speed electric railway operation, however, introduces problems quite its own, and, as Mr. Smith rightly maintains, a special type of motor is called for.

As stated at the outset, the object of the paper was to consider generally the recent development of the railway motor, and, notwithstanding certain inexactitudes of detail which have been duly criticized, I think that this end has been served. The discussion has put us in possession of a number of new and useful facts, and I trust that the subject may be expanded at a later date by a paper from one of our electric railway engineers discussing the matter from the operating point of view. In regard to the higher voltages, these are working out their own salvation, and such installations as the new line in Lancashire will be carefully watched by all who are interested in the development of electric railways in Great Britain.

\* Page 521.

## DISCUSSION ON

## "THE DEVELOPMENT OF ELECTRIC POWER FOR INDUSTRIAL PURPOSES IN INDIA." \*

CALCUTTA LOCAL CENTRE, 27 MAY, 1915.

Mr. A. K. TAYLOR: I should like to make a few comments on this paper as it appears to one who, though not connected with the supply of power for industrial purposes on a large scale, has spent 10 years in the Presidency of Bengal engaged in Government electrical work. In the first place, this paper was written in 1913, and as it was received in London in July 1913, it is probably at least two years old. Although the opinions expressed by the author on British electrical engineers in this country may in some cases have carried conviction 5 or 6 years ago, I do not think they can be considered to have been valid at the time the paper was written. The paper itself does not seem to give a correct impression of what has been done in India by British firms. Thus, in his list the author has omitted the following not unimportant electrical concerns, which represent approximately 16,320 kw. :—

Calcutta Tramways Company ... ..	3,850 kw.
Cawnpore Electric Supply & Tramways	1,455 "
H.H. Nizam of Hyderabad's power station ... ..	3,000 "
Khargpur (Bengal & Nagpur Railway)	1,360 "
Lahore (North-Western Railway) ...	1,500 "
Madras Electric Supply & Tramways	3,500 "
Delhi Electric Supply & Tramways ...	760 "
Lucknow (Oudh & Rohilkhand Railway)	900 "

Further, although perhaps not coming strictly under the category of electrical plant, attention may be called to the fact that all the electric motors—representing at least 35,000 kw.—for utilizing the supply provided by the Tata scheme in Bombay were made by a well-known British firm. Also, although it does not come under the head of public supply or tramways, it may be noted that several mills in Calcutta have installed electrical plant of British manufacture, e.g. Hastings Mill, Rishra, where something like 3,000 kw. of electrical plant is installed. Finally, the scales chosen for the ordinates of the curves in the paper tend to give an incorrect idea of the relative increases in electric and steam-driven plant in India.

Mr. C. H. R. THORN: The first part of the paper consists mainly of an exhortation to British manufacturers to "wake up" and to send representatives who know their business to India, thereby tending to convey the impression that the present representatives are not of the right type. This is, of course, merely a repetition of articles and letters which appear in the technical Press from time to time, written as a rule by disappointed representatives themselves, and it need not be taken very seriously. I think the author must have been exceptionally unfortunate if, when he has had occasion to call for tenders,

he has been able to obtain only f.o.b. or c.i.f. prices, as I believe that practically all the British firms represented in India have for several years regularly quoted f.o.r. Indian port, or, if desired, delivery to actual site. With regard to the particulars given under the same heading in connection with the five most important electric supply undertakings in India, it may be pointed out that the two largest of these, the Tata and Mysore schemes, are hydro-electric, and that therefore, as far as the prime movers are concerned, Continental, and especially the well-known Swiss firms, hold a natural advantage, owing to the greater scope for hydro-electric plants on the Continent than in the United Kingdom. With regard to the electrical plant, the author mentions that *no less than* 32,000 kw. was supplied by Germany. Table 1 shows that this 32,000 kw. of plant consists *merely* of that supplied for the Tata scheme (the reference to the United States in the last column of the table obviously refers to the transformer plant and not the generating plant, which is German). Also, judging from the particulars given in Table 1, it would appear that Great Britain supplies only a very small proportion of the electrical plant and materials imported into India; it happens, however, that the author has selected three large plants which tend to give this impression. By referring, however, to the first table in Professor Everett's recent Address as Chairman of the Calcutta Local Centre,\* it is evident that this is not the case and that the United Kingdom holds the bulk of the electrical trade with India. In view of the figures in that table, the author's case against British manufacturers must, I think, fall to the ground.

Mr. A. C. COUBROUGH: I feel that an entirely wrong impression is likely to be created by the statements made in this paper. To anyone unacquainted with the actual state of the electrical industry in India, the general impression on reading the paper would be that Great Britain is a very long way behind her Continental competitors in every direction. In the first two paragraphs of the paper the author criticizes very severely in general terms British commercial methods. One would be led to imagine that not a single British electrical manufacturing firm is adequately represented in India. The impression given is that Continental methods of manufacture are very much superior to British methods, and that Continental firms have studied the particular requirements of the Indian trade from a technical point of view and have standardized their machines accordingly in a way which British manufacturers have failed to do. Under his second sub-heading the author deals with the question of Continental competition and states that "during the last few years a very great proportion of the electrical plant installed in India . . . has been supplied from the Continent." To support

\* Paper by Mr. H. R. Speyer (see vol. 53, p. 597, 1915).

\* Journal I.E.E., vol. 53, p. 467, 1915.

Mr.  
Coubrough.

this statement he then proceeds to give instances of the plant installed at the power stations of several large companies. Mr. Thorn has already referred to the figures in Table 1 and on page 598 (vol. 53) of the *Journal*, and Mr. Taylor has also stated that these figures are rather misleading. In addition to the figures which Mr. Thorn has quoted from Professor Everett's recent Address, I should like to draw attention to the actual relative position of British and German trade in India, which can readily be obtained from the figures published by the Commercial Intelligence Department. From these figures we find that during 1908-9 the total value of electrical machinery imported into India was approximately 36 lacs (£240,000), and of this amount Germany's share was Rs. 69,000 (£4,600). In the following year the figures were approximately 32 lacs (£213,333) total and 1 lac (£6,666) from Germany. In 1910-11 the total was approximately 42 lacs (£280,000), of which Germany's share was 7 lacs (£46,666); and in 1911-12 the total was approximately 42 lacs (£280,000), Germany supplying plant to the value of  $4\frac{1}{2}$  lacs (£30,000). For the next three years up to the end of March 1915 the total imports of electrical machinery were 36 lacs (£240,000), 52 lacs (£346,666), and 53 lacs (£353,333) respectively. During these last three years I have been unable to ascertain the amount of Germany's trade, but as the figures are later than those on which the author bases his arguments, they are not material to my contentions. I think the above figures prove conclusively that the author's statement that "a very great proportion of the electrical plant installed in India, together with its component parts, viz. hydraulic and steam turbines, has been supplied from the Continent" is not borne out by the facts. Great Britain supplies between 80 and 90 per cent of the total electrical machinery sent yearly into India. The author further proceeds to run down British machinery in no measured terms on account of what he considers to be its inferiority from the technical point of view. Now I do not wish it to be understood that I deprecate criticism of British methods or comparison with Continental methods. I am thoroughly in sympathy with fair criticism and with a frank statement of the deficiencies of British manufactures, such for instance as is given in the paper recently read before the Institution by Mr. J. H. Rider.\* Criticism such as Mr. Rider makes leads to the development of the electrical industry as a whole, and urges British manufacturers to greater efforts so that they may not fall behind in competition with Continental or other makers. Mr. Speyer, however, in his paper takes up an entirely different attitude, and as already pointed out, he gives one the impression that British trade in India is nowhere and that Continental manufacturers are ahead in every direction. Such statements, if uncontroverted, would in my opinion do much harm to British interests in this country. If this paper is allowed to remain uncriticized by British manufacturers in India, it will be assumed by the average purchaser of electrical plant in India that he can do better for himself by purchasing Continental machinery. He will receive the impression that he will not only get better machines, but that he will get better attention, that he will get quicker delivery, and that he will be in the hands of representatives of Con-

tinental firms in India who are more alive to his interests than the representatives of British firms. The author says, "It must also be borne in mind that Continental makers are fully alive to the conditions under which electrical plant has to work in India, and have spent both time and money in experiments before deciding on the standardization of plant intended for export to a tropical country. Except in some isolated cases, however, the same cannot be said of the majority of British electrical manufacturers, or else the author's experience has been unfortunate." In connection with this bold statement in favour of Continental machinery I should like to ask what has been the author's experience? For several years prior to the date of this paper the author represented in India the interests of the Lahmeyer Electrical Company, and latterly, on the amalgamation of this Company with the A.E.G. Company, the interests of the combined concerns, which were known as the A.E.G. Lahmeyer Company; and I should like to know what value can be put on the criticisms of British machinery by the representative of that Company. The author states that his experience of British electrical manufacturers may have been unfortunate, but I should feel inclined to say "non-existent," and as a representative of a British firm I resent the author's sweeping, and, I believe, unwarranted criticism of British manufacturers. From time to time one hears of breakdowns of machinery in this country. Knowledge of failure travels fast, and it is everyone's business to find out faults in their competitors' machinery to prove that it is not as good as their own. On the whole, I think I am safe in saying that the breakdowns of electrical machinery in this country are comparatively infrequent, and that the purchaser placing his orders with a sound concern can rely on getting machinery which is designed for tropical service, and which will give him excellent results. Of those breakdowns which have come to my knowledge not a small proportion have been breakdowns of German-made machinery. Statistics of this kind are not easy to obtain, but I am fairly confident that if a record were made of the breakdowns of electrical machinery in relation to the total amount of machinery installed, German-made material would show up very badly. In conclusion, I think it is a matter of the utmost importance to British electrical trade in this country that we should not allow the author's paper to remain as a part of the Institution records without a loud disclaimer from the section of the British electrical manufacturers represented in this country.

Mr. C. B. CHARTRES: In my opinion the paper contains many inaccurate general statements and undeserved criticisms of a large section of the commercial community in this country. Taking first the large hydro-electric power companies, the reason why the generating plants were ordered in America and on the Continent of Europe was the common-sense one that firms in those Continents had had much experience in building such plants, whereas the natural features of Britain have not given opportunities to British makers to standardize large hydro-electric plants. Coming next to the mill power-supply question to which so much of the paper is devoted, I consider the statements that "mill-owners and their engineers . . . regard with keen disfavour electric plant" and that they adopt an antagonistic attitude to changes to be quite untrue. I have always found mill managers and engineers in this country

\* *Journal I.E.E.*, vol. 53, p. 609, 1915.

to be only too pleased to consider new schemes which promise economy, and if the proposed scheme be a good one they do not hesitate long before adopting it. The author ought certainly to be aware that at any rate as far as jute mills are concerned his indictments are incorrect. The mill industry in India is a very important one, but the working conditions at the two main groups of mills in the Bengal and Bombay Presidencies are so totally different that general statements cannot be made to apply accurately to both groups. It will be appropriate to consider here only the jute mills round Calcutta and whether they deserve the author's imputation of lack of enterprise. Practically all the mills are of the single-storey type with well laid-out rope drives to the various shafts operated from a main steam engine; and as most mills have the boilers close to the engine room, radiation losses are small and the power plants are fairly economical. In fact I should think the Calcutta mills have the cheapest power of any mills in the world, and no scheme for supplying electricity to them in bulk could ever prove profitable to both the supply authority and the mill owners. The author ought to have realized that this was the real reason for the Mourbhunj hydro-electric scheme being shelved, and not the lack of British enterprise in connection with the scheme. In support of this statement it may be mentioned that with fuel at Rs 6 (8s.) per ton the cost of coal in existing mills generally does not exceed 0.125 anna (0.125d.) per i.h.p.-hour for the power plant itself. This is equivalent to 0.225 anna (0.225d.) per kilowatt-hour of electrical energy if motors be installed to supersede the engine drive; and as labour costs would be practically equal in both cases, it follows that to show any economy by electric driving in a mill with existing steam plant and to provide for the extra capital charges involved, electricity would have to be supplied at less than 0.2 anna (0.2d.) per unit at the mill distribution-board. No power company could profitably do this. With regard to electric driving from a private generating plant, I have had opportunities of considering several schemes, and in most cases I have found that the extra capital charges for new plant would absorb all the economies to be effected in running costs, so that it would not be economical to "scrap" an existing steam plant in a fairly modern mill and replace it by electric driving. Of course in cases of extensions or of new mills the matter is different and electric driving offers good results, but if the mills are to obtain maximum economy they must install their own generating plants, unless the supply company is prepared to reduce considerably its present rates. A private turbo-generating plant of, say, 1,500 kw. at a mill on the Hooghly can easily produce electrical energy at not more than 0.25 anna (0.25d.) per unit, including all capital charges, and working only 80 hours per week. The author appears to think that if a jute mill be electrically driven with power from a supply company all steam plant can be dispensed with, but this is

not the case, for boilers are still required to supply steam for process work in the mill and for fire pumps, etc. In fact the coal used for such purposes is a large proportion (generally about 20 per cent) of the total coal now used in a steam-driven mill. Coming now to electric plants which have already been installed, I should like to know to which two plants the author refers as having been reconverted to steam driving. He appears to blame the contractors for this, and also for sundry other troubles, but my experience is that most of the faults with electric plants out here have been caused by bad engineering on the part of those responsible for the design of the installations rather than by faults due to bad design or workmanship in the machinery itself. With regard to the statement in the paper that many firms refuse to quote for a plant completely erected, the author must not conclude that this is the general custom. Many British firms quote for and carry out complete schemes whenever required. The author's remarks about the comparative value of agents and direct representation are the only part of the paper with which I really agree, but he subsequently spoils their effectiveness. Throughout the greater part of the paper he complains that mill-owners will not electrify their plant, and then he states in the paragraph under consideration that if a firm did get a contract for electrifying a mill they would have to send out their best engineer to nurse the job for 18 months or two years after starting. Could anyone possibly give a mill-owner a better reason for declining to electrify? Fortunately, if left to themselves, the British firms established here do not turn out jobs which require much nursing.

Mr. W. G. HENDREY : Some of the assertions contained in the paper give, as they stand, an altogether erroneous impression with regard to the conditions of the electrical trade in India as far as British manufacturers are concerned. In particular, the author's experience with regard to the prevalence of quotations based upon f.o.b. and c.i.f. rates cannot be taken as representing the general practice of British manufacturers, as a body, in this country. It is common knowledge that quotations are obtainable from a large number of the Indian branches of British manufacturing companies, with prices that include delivery either on the site or on the rail, and quotations providing for complete erection can be readily obtained. The paper is dated 1913, but its publication at the present time must produce amongst those not actually on the spot, a distorted view of the present conditions of the Indian trade, unless some of the assertions contained in it are disputed.

Mr. A. K. TAYLOR : In closing this discussion, I wish to endorse the opinions of Mr. Thorn, Mr. Coubrough, and Mr. Chartres, and of this meeting generally. I would emphasize the fact that the members of this Local Centre dissent from the views expressed by the author and consider them damaging to their best interests.

## DISCUSSION ON

## "THE USE OF CONTINUOUS CURRENT FOR TERMINAL AND TRUNK-LINE ELECTRIFICATION." \*

Mr. Storer.

Mr. N. W. STORER (*in reply, communicated*): I have been much gratified by the discussion of my paper, particularly at this time when the war is absorbing the attention of everyone to the exclusion of other matters. It was a source of extreme regret to me not to be able to present the paper in person. However, I am sure that the paper lost nothing in its presentation by Mr. Peck, to whom my sincere thanks are due. Owing to the large number who took part in the discussion at the various places where it was presented, and the fact that many of the speakers referred to the same features in the paper, I shall not attempt to reply to each one individually, except where some particular point is brought out.

*Steam versus electric locomotives.*—Mr. Roger Smith supports the position taken in his paper of two years ago as to the relative merits of steam and electric locomotives for high-speed passenger service, by a comparison between a Great Western Railway 4-6-0 steam locomotive and the Pennsylvania New York terminal locomotive, the curves for which were given in the paper. The inference is drawn from this comparison that it is necessary for a high-speed electric locomotive to weigh nearly twice as much and cost nearly four times as much as a steam locomotive for corresponding service. This inference is certainly due to a misunderstanding. The Pennsylvania locomotive was designed primarily for heavy-grade service at moderate speed, and is seldom or never required to exceed a speed of 60 miles per hour. It cannot, therefore, be taken as a representative high-speed locomotive. It is admirably suited to the work for which it is used, which consists in hauling trains of 500 to 700 tons trailing load through the tunnels under the rivers at New York, where the grades are  $1\frac{1}{2}$  to 2 per cent. The locomotives are frequently called upon to develop tractive efforts up to the limits of adhesion, and their maximum tractive efforts are, therefore, none too large for the service. It is therefore impossible to make a fair comparison between these two locomotives. All that we can reasonably infer from it is that while the electric locomotive is able to do practically anything that the steam locomotive can do, it would take three steam locomotives to perform the work of one of the electric locomotives. It is apparently necessary that any locomotive, whether steam or electric, that is used for very high speeds should be specially designed for that service, and undoubtedly an electric locomotive could be designed for the high-speed service performed by the Great Western steam locomotive that would be very much cheaper and lighter than the Pennsylvania locomotive. It might in fact be not much more than half as heavy. The present difficulty of comparing steam and electric locomotives for high speeds lies in the fact that there have been very few cases where electric locomotives have been designed primarily for high-speed service, and I am sure that if the problem of an electric locomotive for handling the service on the Great Western

Railway were submitted to the manufacturers, a satisfactory solution would be reached.

Dr. S. P. Smith questioned the suitability of the series motor characteristics for high-speed service, but I do not understand in what respect it fails to meet his expectations, unless he assumes the inference drawn from Mr. Roger Smith's discussion that it is necessary for the electric locomotive to have an enormous excess capacity at the lower speeds in order to develop the required tractive effort at high speeds. I believe I have shown the error in that argument. It is a simple matter electrically to secure the required output at high speed without an excess at low speeds, although due to the inherent characteristics of the electric motor it will always have a capacity sufficient to develop heavy overload tractive efforts for short periods.

Mr. Lydall made a good point in bringing out the fact that the variation in speed by field control is much less for a certain tractive effort than for a given horse-power. This is really what is desired in service, and shows clearly the advantage of the electric locomotive which maintains speed on grades much better than steam locomotives. The heavy short-time overload capacity of the electric locomotive is a very valuable characteristic.

*Motor characteristics.*—Referring to Mr. Lydall's 1,500-volt motor calculation, he will probably find that the long magnetic circuit due to a small number of poles has a good deal to do with the flatness of the speed curve. The Pennsylvania Railroad motor has 10 poles with a fairly low degree of saturation. Probably also the wider polar arc and the length of air-gap of the 1,500-volt motor affects the speed. The shape of a speed curve is, in general, simply a matter of carefully proportioning the magnetic circuit.

Mr. Lydall also mentions some calculations he had made on a motor wound for 1,500 volts and claims that insulating this same motor for 3,000 volts increased the  $D^2 L$  by 40 per cent. While undoubtedly the space factor will be less for the motor when insulated for 3,000 volts, I do not think that it should be necessary to make such a large increase in the armature dimensions.

*Regenerative control.*—Various questions have been asked in regard to the details of the regenerative system which was mentioned in the paper. I am glad to be able at this time to give a brief outline of the system and of the auxiliary apparatus required for it. As stated in the paper, it is used in connection with the regular series motors. When regenerating, the motors are separately excited from a motor-generator or other source of low voltage, and the field current is varied by a rheostat which may be controlled either by hand or automatically, as desired. Stability and immunity from flashing or other troubles due to fluctuations in line voltage are ensured by the use of a resistance which is common to both the field and armature circuits, these currents passing through it in parallel. It will therefore be seen that an increase in

\* Paper by Mr. N. W. Storer (see page 521).

armature current will increase the drop in voltage through this resistance, and consequently will tend to reduce the field current, thus lowering the generated voltage and the armature current. Conversely, a decrease in armature current will increase the field current. The motor operating as a generator may be arranged to regenerate successfully on any given control notch over quite a wide range of speed or line voltage without danger from surges in current and resulting flash-over. All that is necessary is to have a proper value for the common resistance and to have the control arranged to function properly. The auxiliary apparatus required, in addition to the regular control, consists of a motor-generator or other suitable source of low-voltage current for exciting the fields, an air-operated cylinder or drum-type controller for varying the resistance in the field circuit or the voltage of the exciter, a change-over switch consisting of another drum-type controller operated by air which changes the necessary control and main circuits when changing from acceleration to regeneration, and vice versa, and a few unit switches and relays. The motor-generator set, rheostatic controller for fields, change-over switch and five unit switches added to the 20 switches shown in Fig. 9 in the paper, will equip the car both with field and regenerative control, so that the additional apparatus required will not be at all serious.

The question of motor capacity required for regenerative equipments has been raised. It is certain that larger motors must be used, or some other means be taken for meeting the requirements of the extra duty imposed by regeneration. Where the motors are as large as can be used on the trucks, which is the case only where trailers are handled, more motors or motor-cars must be used in the train unless forced ventilation is adopted. The increased capacity needed will depend entirely on the service in which the motors are to be used. Where frequent stops are necessary, a relatively large amount of regenerative braking will be required and the capacity of the motor may have to be 20 to 25 per cent greater than would be necessary for accelerating only. This can sometimes be obtained by the use of a blower driven by the motor-generator set, but in general it will be found better to increase the size, or number, of the motors used. It must be remembered that one can seldom get something for nothing, and a saving of 20 to 25 per cent in the energy used for operating a railway is certainly worth some additional investment.

The question has been asked as to the precautions that are being taken to avoid the difficulties that have been experienced with the Raworth system which generated excessive voltages and burnt out the lamps on the cars in cases where the trolley left the wire or regeneration was otherwise stopped. The equipment proposed is thoroughly safeguarded to avoid either excessive voltages or danger from the train running away on a down grade in case of stoppage of the regenerative current for any reason. In the former case, the field circuit of the motors would be automatically opened before the voltage could reach a dangerous value, and in the latter case the air brakes would be automatically applied.

The value of the saving in energy by regeneration with locomotives has been questioned, since it is sometimes necessary to use a resistance in the power station to absorb

this energy. This will, of course, be the case in any small system where it is occasionally found that only one train is on the line and that one descending a grade and regenerating. The tendency of the times is towards the use of large central power stations to furnish power not only for private consumers but for railways and other large users. In such a case there would always be a load on the line which would absorb any regenerated current.

Mr. Firth has inquired if this system is suitable for multiple-unit service. Mr. Peck has answered in the affirmative and I wish to confirm this. It is probable that it will in the near future be applied in actual service on heavy multiple-unit trains, as well as on locomotives. For multiple-unit service the control is so designed as to be entirely automatic from the time the master controller is thrown to the regenerative position until the train comes to a standstill or, at the will of the motorman, is allowed to operate at a lower speed by interrupting the progress of the controller. The regeneration will continue automatically through the higher speeds with the motors in parallel. When the lowest parallel speed is reached, the motors are changed automatically to series without opening the circuit and regeneration continued until the lowest regenerating speed is reached, after which the air brakes will be automatically applied and the control circuits opened.

The field for regenerative control will be found in the heavy multiple-unit service with frequent stops, and in locomotive service where long heavy grades are encountered. It is doubtful whether the value of regeneration for small tramway equipments would be sufficient to pay for the additional complications and weight of the equipment required.

**Field control.**—This question has been discussed very fully and a number of valuable points brought out. Mr. Carter especially has given an excellent idea of the advantages and disadvantages of field control. The main question is in regard to the increased weight and cost of motors arranged for it. If motors are to be used in stopping service where the work is practically all that of acceleration, the field-control motor will be very little heavier than the single-field motor for the same service. The armature should be wound for a lower speed, assuming that the same gear ratio is used in both cases, and would therefore have a lower kilowatt rating, but it will develop the required tractive effort with a smaller current and with practically the same loss in the motor, and will therefore be able to handle the service with the same heating. The reason for this lies in the fact that the average voltage applied to the armature terminals of a field-control motor in accelerating to a given speed is higher than that of the non-field-control motor, and consequently the average current taken from the line is smaller.

If, however, field control is used as a means of securing additional speeds on a locomotive, and a kilowatt rating of the motor is determined by the power required to run at its highest speed for a considerable time, the motor will undoubtedly be heavier and more expensive, since it must have the same kilowatt rating as the single-field motor and must cover a range of speed with this rating by varying the field strength. A non-field-control motor might, for instance, be able to develop the required output at a speed of 500 r.p.m., but the field-control motor must, assuming again the same gear ratio, be able not only to develop the

Mr. Storers. output at 500 r.p.m., but at a lower speed, say 400 r.p.m. In other words, the weight and cost of the field-control motor must be determined by the service in which it is to be used, and no general statement can be made that will apply.

*Speed-torque gear.*—Mr. Sayers suggests the use of a "speed-torque" gear in order to improve the efficiency of acceleration and increase the number of efficient speeds. Such a device would be of the greatest value if it could be made practicable for use with large locomotives. As I am entirely unfamiliar with the devices named, I am unable to form an opinion as to their merits. I have, however, known of one or two similar devices which when applied with heavy powers become so expensive and cumbersome as to be prohibitive.

*Twin-armature motors.*—The question has been raised by several as to the feasibility of the 5,000-volt twin-armature motor which was described in the paper, for application to the ordinary car trucks. The motors now in service are rated at 100 h.p. each, and there is no difficulty in mounting them with sufficient clearance on wheels of 36 in. to 37 in. diameter. Motors of 150 h.p. can be mounted on wheels 40 in. in diameter. Mr. Pannell speaks of 20 in. as the ordinary diameter of large size car motor armatures, and assumes that 12 in. is the maximum diameter that can be used with 40 in. wheels for the twin-armature type. It must be remembered that each of the twin armatures is required to develop only half the output of the single larger armature. There is no doubt that the twin-armature motor is hampered to a certain extent by its height; otherwise, however, it takes less space than the single-armature motor.

Mr. Pannell's curves show very clearly the limitations of the 4-pole motor in voltage, and especially that the maximum voltage is a function of the size of motor. Undoubtedly more than 1,500 volts can be used on a single armature in some cases, but it is the general case that must be considered as the determining factor in the voltage for railway service. If it is found desirable for other reasons to adopt a voltage of 2,400, or over, for a continuous-current railway, it will be found that the twin-armature motor has very decided advantages.

*Standardization.*—This question seems to have aroused more discussion than anything else in the paper, and quite properly, since it is of such far-reaching importance. While everyone seems to agree with the views expressed in the paper as to the difficulties and dangers involved by a multiplicity of contact systems and voltages or kinds of current, a good many seem to feel that the time is not ripe for standardization. I agree entirely that no one man is to-day in a position to say what is the best contact system or best voltage. That is why I recommend a committee. I agree with Mr. Merz that it is necessary to decide between third rail and overhead system before the voltage or kind of current can be determined for main-line work. But cannot this decision be accelerated by a competent committee?

Everyone is agreed that a pressure of 600 volts is too low for trunk lines, and that the voltage on the 600-volt type of third rail cannot be materially increased. That means that the adoption of a third rail for the main lines would necessitate changing all the present 600-volt rails where it is necessary to operate main-line cars. In that

case, assuming that a voltage not exceeding 1,500 were used, it would probably be possible to do as Mr. Firth suggests and raise the existing third-rail lines to that value. That would give complete interchangeability between suburban and main lines—in fact, one uniform system for everything. This hinges on the possibility or desirability of using a 1,200- or 1,500-volt third rail, and on this being a high enough voltage for the long lines. Of course, there is a possibility of using an overhead conductor in connection with the 1,500 volts where the third rail is undesirable, but this would hardly be practicable for trunk lines except for short distances.

If the 600-volt system is to be continued, as seems highly probable and to most people desirable, it will be a great handicap to any other system adopted for main-line work. As pointed out in the paper, it is not desirable to attempt full speed on 600 volts, if the equipments are designed for more than double that voltage. Mr. Firth feels that main-line equipments must operate at full speed over suburban tracks. If this is the case, it would be practically necessary to double the voltage on the present lines in order to secure a voltage anywhere near high enough for main-line work on overhead trolley, assuming that 2,400 is the lowest practicable voltage for main-line operation with overhead trolley.

I am glad to note that the plan of having the suburban and main line systems made entirely independent by the use of both contact systems on tracks common to both lines, met with the support of a number of the speakers. I believe the plan is one that deserves the most careful consideration, and that the saving in equipments will more than balance the cost of the double contact system. Such a plan would make it possible to adopt for the main lines either the highest desirable continuous-current voltage or single-phase alternating current.

There seems to have been the impression left by the paper that an immediate and final decision as to standards was recommended. Such was not the intention. In the first place, I know that it would be practically impossible for a competent committee to make the investigation necessary to decide the questions finally in less than two or three years, even if the necessary operating data were all available. In the second place, it would be undesirable to adopt permanent standards in the present state of the art. There is no doubt in my mind, however, that a competent committee could do an immense amount of good by recommending temporary standards, as Mr. Peck said. Certainly such a committee could, after studying the entire situation, be in an excellent position to recommend against a large part of the possible systems so as to prevent their repetition, and could guide the developments so as to arrive at a permanent standard much more quickly than can be done by the more or less haphazard methods at present in vogue in America and Great Britain.

A glance at some of the things that would be considered by the committee will show at once how much good could be done by taking up the question from a national standpoint rather than from a purely local one. It could investigate: (1) The questions of clearance, insulation, and protection for a third rail having a voltage high enough for main-line work; (2) the possibility of using the third rail satisfactorily in yards without auxiliary overhead contacts at crossings and other difficult places; (3) the amount of

trackage which would not permit the use of an overhead conductor at this time, and whether it is impossible to change this, or whether it is simply a matter of cost; (4) the factors determining the most satisfactory height of the overhead wire; (5) the question of a satisfactory voltage for the overhead system, that is, what voltage should be used to secure a good load factor on sub-stations without a large expense for feeder copper; and whether this is a practicable voltage; (6) the costs of the distribution systems when compared on the basis of equal advantages as regards sectionalization, protection, and reliability; (7) comparative first costs and operating costs for the different voltages.

It is necessary and desirable that various systems should be tried out in order to determine their fitness for railway service. When this fitness has been determined, however, new installations should be decided upon with respect to

the fitness of the system for general electrification rather than for the particular one under consideration. That is where the proposed committee should be on hand to steer the railways in the right direction. Even if they were unable to decide upon a temporary standard, they could at least reduce the number of competitors by eliminating those that were unsuited for the general plan. A standard would thus finally be arrived at by process of elimination.

Since writing the paper, I have learned that the Institution has no machinery for carrying out such work, and that all standardization work in Great Britain is done under the supervision of the Engineering Standards Committee. It would seem that if the assistance of this Committee could be invoked, a great deal could be done without hampering the progress of the art, and a final solution for the problems involved could be reached much more quickly, and certainly with a great deal less expense.

## PROCEEDINGS OF THE INSTITUTION.

590TH ORDINARY MEETING, 13 APRIL, 1916.

Mr. C. P. SPARKS, President, took the chair at 8 p.m.

The minutes of the Ordinary Meeting held on 16 March, 1916, were taken as read, and were confirmed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and it was ordered to be suspended in the Hall.

Messrs. J. C. Wigham and M. Farrer were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

### ELECTIONS.

#### Associate Members.

Briggs, John Cockbain.	Partington, George Arnold,
Forder, Ernest.	Corporal, R.E.
Forrest, Henry Robert.	Pettie, Arthur James Scho-
Kingham, Thomas Alfred.	field.
Lofus, James John.	Stanley-Smith, Ralph.
McDougall, Donald.	Watson, William Edward.

#### Students.

Barton, George Elliott.	Milnes, Tom.
Bernard, John Iver.	Pearson, Stephen Oswald.
Brown, Vance Auberon.	Rawll, Reginald Henry.
Doran, William E.	Simpson, Eric William.
Fichzon, Harry A.	Smith, Arthur Robert.
Gee, Colin Brooke.	Waddington, Oswald Ver-
Greenwood, Fred.	non.
Long, William Alfred R.	Wormull, Charles Fred-
Mehrez, Ahmed Mohamed.	erick.

### TRANSFERS.

#### Associate Member to Member.

Cooper, John Sisson St.	Hamilton, C. Norman M.,
George, M.A., B.Sc.	2nd Lieut., R.G.A. (S.R.).
Over, Percy.	Wright, Joseph Henry.

#### Graduate to Associate Member.

Barsdorf, Leonard William.	Pells, Ernest Arthur, Major.
Beck, John Wilson.	R.E.
Browne, Walter Stephen.	Rayner, David Dyson.
Campbell, Randolph Gordon.	Rodger, John Wilfred.
Douglas, William Donald.	Sawtell, Walter Stanley.
Healey, Herbert Clifford.	Smellie, Alfred, Junr.
Jones, Reginald Gomer.	Stent, Thomas Frederick.
Leggett, Bernard John.	Young, Henry Percy.
McCormick, Bernard.	

#### Student to Associate Member.

Abram, William Reginald.	Robinson, Bernard Augus-
Goble, Frank.	tus.
Gregson, Herbert.	Wilson, John Chapman,
Hobson, Harold.	B.Sc.
Johnson, William Geden.	

Messrs. F. B. O. Hawes and E. A. Nash were appointed scrutineers of the ballot for the election of new Members of Council.

The following donations were announced as having been received, and the thanks of the meeting were accorded to the donors:—

*Benevolent Fund:* The Electrical Engineers' Ball Committee, S. W. Melsom, M. G. Simpson, H. A. Skelton, and C. P. Sparks.

*Library:* The Bureau of Standards (Washington), The "Electrician" Printing and Publishing Co., Ltd., Professor A. Hay, D.Sc., H. R. Kempe, W. Perren Maycock, Professor J. T. Morris, H. M. Sayers, Messrs. E. and F. N. Spon, Ltd., F. H. Taylor, and the Union des Syndicats de l'Electricité.

A discussion was held on "The Present Position of Electricity Supply in the United Kingdom and the Steps to be taken to Improve and Strengthen It" (see page 588), and the meeting adjourned at 9.55 p.m.

## 44TH ANNUAL GENERAL MEETING, 11 MAY, 1916.

Mr. C. P. SPARKS, President, took the chair at 8 p.m.

The minutes of the Ordinary Meeting held on 13 April, 1916, were taken as read, and were confirmed.

The President announced that the Scrutineers (Messrs. F. B. O. Hawes and E. A. Nash) appointed at the meeting of the 13th April to examine the ballot papers for the election of new Members of Council reported that 1,058 ballot papers had been returned as against 551 last year. The result of the ballot was that the following had been duly elected:—

*President:* C. P. Sparks.

*Vice-Presidents:* R. A. Chattock and C. H. Wordingham.

*Honorary Treasurer:* J. E. Kingsbury.

*Ordinary Members of Council:* J. O. Callender, F. W. Cawter, J. Devonshire, H. H. Harrison, G. H. Nisbett, W. L. Preece, and W. R. Rawlings.

The Council for the year 1916-17 would therefore be constituted as follows:—

*President.*

C. P. SPARKS.

#### The Past Presidents.

*Vice-Presidents.*

R. A. CHATTOCK.

ROGER T. SMITH.

DR. A. RUSSELL.

C. H. WORDINGHAM.

*Honorary Treasurer.*

J. E. KINGSBURY.

#### Ordinary Members of Council.

J. O. CALLENDER.

G. H. NISBETT.

W. A. CHAMEN.

G. W. PARTRIDGE.

J. CHRISTIE.

W. H. PATCHELL.

F. W. CRAWTER.

W. L. PREECE.

J. DEVONSHIRE.

H. F. PROCTOR.

H. DICKINSON.

G. S. RAM.

J. HUNTER GRAY.

W. R. RAWLINGS.

H. H. HARRISON.

R. J. WALLIS-JONES.

PROF. T. MATHER, F.R.S.

W. B. WOODHOUSE.

AND

The Chairman and Immediate Past-Chairman of each Local Section.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and it was ordered to be suspended in the Hall.

Messrs. E. A. Pinto and C. E. Squire were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

#### ELECTIONS.

##### Associate Members.

Arnett, Charles Thomas S.

Hebden, George Brentnall.

Cresswell, Norris

Jeffreys, Thomas William.

de Wardt, John Chipperfield.

Moore, George, B.Sc. (Eng.)

Eastman, Horace Albert.

Newberry, William George.

Gil, Joseph Valderama.

Nicholson, Charles Henry.

Hart, William Hugh.

Powel, Charles Alfred.

##### Associate Members—continued.

Sandiford, John Henry.

Spicer, Frank Parkinson.

Shumaker, Floyd Newman,

Thrupp, Frederick Ed.

Captain, R.F.C.

ward M.

Singleton, Cuthbert, 2nd

Wakeford, Lionel Thomas.

Lieut., R.E. (T.).

White, Ernest Saunders.

##### Graduates.

Chandler, Charles Kingsley.

Kirkpatrick, Kenneth John.

Fellows, Herbert Sydney.

Mowbray - Hafner, Henry

Furness, William John.

G. A.

Gladly, Thomas.

Pask, Vincent Alexander.

Jones, Charles Edward.

Saxby, Herbert Baker.

Jones, Rice Parry.

Tilley, Horace Henry.

##### Students.

Baker, Frederick Nor-

Payne, Charles Jeffery.

man.

Plowman, Mark Frederick

Body, Howard Thomas.

R.

Hilder, Kenneth Frank.

Ravn, Walter Alfred.

Lloyd, Lewes Sidney H.

Warner, Cecil Etheridge.

##### TRANSFERS.

##### Associate Member to Member.

Atchison, Arthur Francis T.,

Ridgway, Albert Edward

B.Sc.

A.

Browning, William.

Wilkinson, Herbert Tat-

Cooper, Harry.

lock.

##### Graduate to Associate Member.

Bright, Victor Atkinson.

Ramsay, Alfred John.

Little, Douglas.

Turner, Edward Falkland.

McIntosh, Alexander.

Wood, Leonard Ernest.

##### Student to Associate Member.

Carr, Arthur Stephenson.

Mack, Robert Alfred.

Clayton, Brian Charles.

Maguire, Cecil Edmund.

Crompton, Arthur Wesley.

Sleight, Eric William.

Edward, Walter Gordon,

Stubbs, Arthur, B.Sc.

2nd Lieut., R.E. (T.).

(Tech.).

Inglis, William.

Woodrow, William Andrew.

##### Student to Graduate.

Alsford, Charles James

Maidment, Roland Fred-

R.

erick J.

de Hollanda, Raphael.

Spendiff, Bertram George.

Hall, Thomas Haffenden.

Tolley, Henry John.

The following donations were announced as having been received, and the thanks of the meeting were accorded to the donors:—

*Benevolent Fund:* A. Howell, and C. Vernier.

*Building Fund:* A. Hay, and W. McGeoch.

*Library:* The Engineering Standards Committee.

*Museum:* A. A. C. Swinton, F.R.S.

The President announced that the Council had that day awarded the Willans Premium to Dr. S. Z. de Ferranti for his Presidential Address\* to the Institution delivered on the 10th November, 1910.

The President, after referring to the principal items in the Annual Report of the Council,† moved "That the

\* *Journal I.E.E.*, vol. 46, p. 6, 1911.

† See page 550.

Annual Report of the Council as circulated he received and adopted." Mr. F. H. Nalder seconded this resolution.

Mr. W. R. COOPER and Mr. L. JOSEPH asked some questions in regard to the Report, to which the President replied.

The resolution for the adoption of the Report was then put and carried unanimously.

The President then moved "That the Statement of Accounts and Balance Sheet for 1915, as presented, be received and adopted."

After this resolution had been seconded by Mr. P. Rosling, Mr. J. E. Kingsbury, Honorary Treasurer, made a brief explanatory statement with regard to the Accounts, and also answered some questions which had been asked by Mr. L. Joseph.

Mr. W. C. P. TAPPER pointed out that if the assets were written down to their present values there would be a very considerable reduction in the figure set out in the balance sheet.

Mr. J. E. KINGSBURY: The assets are taken in our Accounts at cost price, and thereby we are doing exactly the same as other Institutions of a similar kind to ours, such as the Institution of Civil Engineers and the Institute of Chartered Accountants. The reason for this policy is, I believe, that there is no occasion at present to realize our securities, as might be the case if they were the assets of a bank with the liability that a demand might be made on them at a moment's notice. It is quite clear, I think, that it must be safer and sounder to carry them forward at cost than it would be to take a valuation at the present time, since this would be at least as misleading in the other direction as the cost at which they now stand.

Mr. W. R. COOPER suggested that the figures for the previous year be printed on the margin of the Accounts, so that the figures might be easily compared; and the President replied that the suggestion would be considered by the Finance Committee.

Mr. W. B. ESSON: I think, notwithstanding what the Honorary Treasurer says, the investments ought to be written down somewhat. I do not say they ought to be written down to their values to-day, but they were bought long before the war broke out, and it is quite certain that they will not reach pre-war prices for at least 25 years. It would be very much better if the Council wrote down these investments by, say, a certain small percentage every year, so that eventually they would get somewhat nearer to the correct price than they are to-day. The result of keeping them at their cost price is misleading.

The PRESIDENT: I suggest that the question raised by Mr. Esson be referred to the Finance Committee and the professional Accountants. The Council will be guided by the report made by those two bodies, and next year we can then report what action has been taken.

Mr. W. C. P. TAPPER: I suggest that a note should be put at the foot of the Accounts, stating that the investments were worth so much at a certain date.

Mr. F. H. NALDER: If we write our investments down we ought also, in cases where the investments have risen in value, to write them up. I do not think any public body writes its investments down unnecessarily.

The PRESIDENT: The professional Accountants have felt that this is a difficult matter to deal with, and when the war is over it will have to be faced, but at the present time it is very difficult to express an opinion on the point.

Mr. A. A. C. SWINTON: I should like to point out that in an Institution of this kind there is probably never any reason to realize the investments, and the really important matter is that the income should continue at a fixed figure; so that it really does not matter to an Institution like this what its investments are worth.

Mr. P. ROSLING: I consider Mr. Swinton's to be the correct view of the matter. This is not a business concern; these are income-producing investments, and they can remain in the balance sheet at their present figures.

The resolution for the adoption of the Accounts was then put by the President and carried unanimously.

Votes of thanks to the Honorary Secretaries of the Local Sections, the local Honorary Secretaries and Treasurers abroad, the Honorary Treasurer (Mr. J. E. Kingsbury), the Honorary Auditor (Mr. Sidney Sharp), and the Honorary Solicitors (Messrs. Bristows, Cooke, and Carmichael), in recognition of their services to the Institution during the past year, were then unanimously passed.

Mr. J. E. KINGSBURY: The notice calling this meeting indicates that two auditors are to be elected, but a modification has arisen, owing to particular circumstances, which means that we only elect one of them at this meeting. Last February Mr. Alabaster was compelled, owing to ill-health, to resign his appointment, and the Council selected Mr. W. B. Esson to replace him. Unfortunately Mr. Esson found it impossible to continue in that office, and there has not been time to give the requisite 14 days' notice for the nomination of a successor; so that, whilst it is possible for this meeting to re-elect Mr. Sharp, another auditor cannot be nominated to-day. The Council will, however, be in a position to fill the vacancy, and if members will only give the Council some indication of their wishes in the matter, the Council will carry them out, so that the difficulty is merely a technical one. I wish to point out at the same time a somewhat anomalous position, namely, it has been customary at each annual general meeting to appoint Honorary Auditors but not professional Auditors, and the Council would be glad to hear the views of the members on that practice.

The PRESIDENT: The Council feel that this question of auditing should be entirely in the hands of the members as in the case of a company.

Mr. W. B. ESSON: There is no doubt whatever that the professional Auditors in an Institution like this are the important people to be considered. We have grown into a huge Institution with a very large membership and thousands of accounts to be checked, and it is quite impossible for any Honorary Auditors to do that kind of work. If it is assumed that the Honorary Auditor puts his name to the balance sheet and by so doing takes no responsibility, well and good, but it should be thoroughly understood that that is the case. I might here mention a personal matter. The real reason I was unable to go on with the Honorary Auditorship was that I found the auditing of the Institution's accounts took about eight to ten days' steady work on the part of two men checking the accounts. To put my name to a balance sheet implies very great responsibility, and if my name on the balance sheet were to be worth the paper it was written on I should have to go to the same trouble

Mr. Esson and check the accounts with the same care and go into everything in the same way as the professional Auditors do. That I could not do, and I doubt whether any of the Honorary Auditors have done so in the past. Let it be clearly understood that if anything were to go wrong with the Accounts, the responsibility would not be put on the Honorary Auditors but on the professional Auditors. I propose, therefore, that the office of Honorary Auditor be abolished. My friends in the City say it is a perfectly anomalous thing; such a thing as an Honorary Auditor is never heard of there when you have professional Auditors. It is simply a fifth wheel to the financial coach. It is going something in the direction of what I suggest if you leave one Honorary Auditor and appoint the professional Auditors, but to go on perpetuating this folly by appointing another Honorary Auditor, I disapprove of altogether.

Mr. Kingsbury. Mr. J. E. KINGSBURY: There is at present one vacancy, assuming that Mr. Sharp is re-elected. If this meeting were to indicate that it is their wish that the Council should fill the vacancy with the professional Auditors, then the professional Auditors would come up for re-election before this meeting every year, and there would be the direct appointment of the professional Auditors by the members year by year, which does not exist at present.

Mr. Swinton. Mr. A. A. C. SWINTON: I move that Mr. Sidney Sharp be re-elected Honorary Auditor, and that the Council be

requested to appoint as the other Auditor the firm of Accountants which at present acts for us.

Mr. F. H. NALDER: I second that resolution.

The resolution was then put and carried unanimously.

Mr. S. SHARP: I should like to say that I think Mr. Esson has absolutely misconceived the duties of an Honorary Auditor. An Honorary Auditor does not have to check the professional Accountant. His duty is entirely different. He is elected from amongst the Corporate Members and, as one of them, has to review annually the Accounts of the Institution. I do not suppose anyone imagines that the Honorary Auditors go through every voucher and figure. What they do is to inspect the arrangement of the Accounts; they watch the increase or decrease in the expenditure and revenue, and seek the reason why it occurs; they survey generally the ledger accounts; they check the bank balances; and, what is perhaps of more importance than all, they see that the property of the Institution, whether represented by title deeds, certificates of investment, or inscribed stock, is still in being and is each year in the possession of the trustees. Mr. Esson's idea of what an Honorary Auditor should be and my idea of the same are entirely different. The professional Accountants are absolutely responsible for the accuracy of every figure in the Accounts; the Honorary Auditors are not.

The President having thanked Mr. Sharp for his explanation, the meeting terminated.

#### SPECIAL GENERAL MEETING OF CORPORATE MEMBERS, 25 MAY, 1916.

Mr. C. P. SPARKS, President, took the chair at 5 p.m.

The notice convening the meeting having been taken as read, the President explained the object of the meeting and then moved the following resolution:—

"That the following words be added to Article 41 of the Articles of Association, namely:—

"(a) On and after the 15th day of June 1916 no person, whether a naturalized British subject or not, who is or shall be or has or shall have ever been a subject of a Country or State, then or thereafter at War with His Majesty or his successors, shall be or continue to be or be eligible for election as a member of any class of the Institution, provided nevertheless that the above disability shall not apply to a person who having at any time

been a subject of such a Country or State as aforesaid shall have become and shall be a naturalized British subject and shall prove to the satisfaction of the Council that under the laws of such Country or State he has ceased to be and is not a subject thereof."

The resolution was seconded by Mr. C. H. Wordingham, Vice-President; and after Captain O. T. O. Webber, Mr. C. A. Baker, and Mr. C. C. Atchison had spoken, the resolution was put to the meeting and carried with one dissentient, the attendance being 46 members.

The President announced that a further Special General Meeting of the Corporate Members would be held on Thursday, 15 June, when the resolution would be submitted for confirmation as a special resolution.

The meeting then terminated.

#### SPECIAL GENERAL MEETING OF CORPORATE MEMBERS, 15 JUNE, 1916.

Mr. C. P. SPARKS, President, took the chair at 5.15 p.m.

Before proceeding with the business before the meeting, the President asked those present to pass the following resolution, the members standing in silence:—

"The members of the Institution of Electrical Engineers have learned with profound regret the death of Dr. Sil-

vanus P. Thompson, F.R.S., a Past President of the Institution, and hereby desire to express their most sincere sympathy with Mrs. Thompson and her family in the great loss which they have sustained through his death, and at the same time to record their deep appreciation of the invaluable services rendered by Dr. Thompson in the

advancement of Electrical Science and its Applications."

The notice convening the meeting having been taken as read, the President moved the following resolution :—

"That the following words be added to Article 41 of the Articles of Association, namely :—

"(a) On and after the 15th day of June 1916 no person, whether a naturalized British subject or not, who is or shall be or has or shall have ever been a subject of a Country or State, then or thereafter at War with His Majesty or his successors, shall be or continue to be or be eligible for election as a member of any class of the Institution, provided nevertheless that the above disability shall

not apply to a person who having at any time been a subject of such a Country or State as aforesaid shall have become and shall be a naturalized British subject and shall prove to the satisfaction of the Council that under the laws of such Country or State he has ceased to be and is not a subject thereof."

The resolution was seconded by Mr. L. B. Atkinson, and on being put to the meeting was carried with one dissentient, the attendance being 31 members.

A vote of thanks to the Chairman having been moved by Mr. L. B. Atkinson, seconded by Mr. A. A. C. Swinton, and carried with acclamation, the meeting then terminated.

## BENEVOLENT FUND.

### ANNUAL GENERAL MEETING, 11 MAY, 1916.

Mr. C. P. SPARKS, President, in the chair.

The President read the Report (see page 672) of the Committee of Management and moved that the Report and Statement of Accounts for 1915 be adopted.

Mr. J. E. Kingsbury seconded the resolution, which was carried unanimously.

On the motion of the President, the Honorary Auditors, Mr. J. Attfield, F.C.A., and Mr. Sidney Sharp, were unanimously re-elected.

The President announced the names of the Committee of Management for the year 1916-17 as follows :—

The President (Mr. C. P. Sparks).

W. Duddell	}	Representing the Council.
J. S. Highfield		
J. E. Kingsbury		
Dr. A. Russell		
Sir John Snell		
W. B. Woodhouse	}	Representing the Contributors.
W. B. Esson		
K. Hedges		
Major W. A. J. O'Meara		

The meeting then terminated.

### GENERAL MEETING OF CONTRIBUTORS, 11 MAY, 1916.

Mr. C. P. SPARKS, President, in the chair.

The notice convening the meeting having been taken as read, the President moved "That the following alterations be made to Rules 9 and 10 respectively of the Rules of the Fund, namely, that the words in italic type be deleted and those in heavy type added :—

"RULE 9.—For conducting the affairs of the Fund there shall be a Committee, to be called the Committee of Management, *consisting of ten Members, and composed constituted* as follows :—The President for the time being of the Institution of Electrical Engineers, six Members of the Council for the time being of the said Institution, **the Chairman for the time being of each Local Section of the Institution in the United Kingdom**, and three Contributors to the Fund, who shall be Members, Associate Members, or Associates of the said Institution, but who shall not be members of the Council thereof. No member of this Com-

mittee shall serve for more than three years consecutively.

"RULE 10.—The members of the said Committee of Management, other than the President of the Institution of Electrical Engineers, **and the Chairman for the time being of each Local Section of the Institution in the United Kingdom**, shall be elected annually by the Council of the said Institution at a Meeting of the Council prior to the Annual General Meeting of the Contributors."

Mr. W. B. Esson seconded the resolution, and after Mr. W. C. P. Tapper had made a few remarks the resolution was put and carried unanimously.

The President announced that a further General Meeting of the Contributors to the Fund would be held on the 15th June, when the resolution would be submitted for confirmation as a special resolution.

The meeting then terminated.

## GENERAL MEETING OF CONTRIBUTORS, 15 JUNE, 1916.

Mr. C. P. SPARKS, President, in the chair.

The notice convening the meeting having been taken as read, the minutes of the General Meeting of the 11th May, 1916, were also taken as read, and were confirmed and signed.

The President proposed: "That the resolution passed at the General Meeting of Contributors held on the 11th

May, 1916, to amend the Rules of the Benevolent Fund in the manner set forth in the notice convening the said meeting, be and is hereby confirmed."

The resolution having been seconded by Mr. S. Sharp, was put to the meeting and carried unanimously.

The meeting then terminated.

## REPORT OF THE COMMITTEE OF MANAGEMENT FOR THE YEAR 1915.

## CAPITAL.

The Capital Account stood on the 31st December last at £3,642 3s. od., all of which is invested.

## INCOME.

The Statement of Accounts shows that the total receipts during 1915 were as follows:—

	£	s	d.
Dividends on Investments ... ..	175	3	7
Interest on Deposit ... ..	8	11	2
Annual Subscriptions ... ..	106	19	0
Donations of £5 and over ... ..	373	10	0
Donations under £5 ... ..	46	13	7
Legacy from the late Mr. Augustus Stroh ... ..	250	0	0
	<u>£960</u>	<u>17</u>	<u>4</u>

## SUBSCRIBERS AND DONORS IN 1915.

## ANNUAL SUBSCRIBERS.

H. Alabaster	K. Hedges
G. F. Allom	J. S. Highfield
S. Beeton	H. C. Holroyd
R. A. Chattock	E. S. Jacob
W. Church	Dr. G. Kapp
F. W. Clements	W. T. Kerr
W. C. Clinton	J. E. Kingsbury
W. W. Cook	H. W. Kolle
V. K. Cornish	A. E. Levin
The Hon. E. H. Cozens Hardy	Sir Henry Mance, C.I.E.
I. S. Dalgleish	J. W. Meares
F. R. Davenport	S. W. Melsom
B. Davies	L. B. Miller
F. E. Davies	W. M. Mordey
M. Deacon	W. M. Morrison
Sir A. Denny, Bart.	K. A. Mountain
J. Devonshire	W. C. Mountain
H. C. Donovan	A. J. Newman
B. M. Drake	Col. A. M. Ogilvie, C.B.
Dr. C. V. Drysdale	C. Oliver
W. Duddell	E. Parry
K. Edgcombe	The Hon. Sir C. A. Parsons,
W. V. Edwards	K.C.B.
S. Evershed	W. H. Patchell
M. Farrer	F. S. Payne
E. Garcke	S. L. Pearce
F. Gill	A. H. Preece
Dr. R. T. Glazebrook, C.B.	W. L. Preece
G. F. C. Gordon	N. Prentice
F. E. Gripper	H. F. Proctor
C. W. Gwyther	G. S. Ram
H. T. Harrison	T. Rich
C. C. Hawkins	R. R. Robertson
W. C. C. Hawtayne	S. R. Roget

## ANNUAL SUBSCRIBERS—continued.

S. A. Russell	H. W. Sullivan
S. G. C. Russell	W. C. P. Tapper
E. Seddon	E. E. Tasker
S. Sharp	W. W. Thomas
J. F. Shipley	C. H. R. Thorn
A. Siemens	A. P. Trotter
M. G. Simpson	H. D. Wilkinson
H. A. Skelton	J. H. Woodward
Sir John Snell	C. H. Worthingham
C. Stewart	H. E. Yerbury
A. J. Stubbs	W. Young

## DONORS.

P. F. Allan	H. L. Leach
J. Ardron, C.B.	H. C. Levis
L. B. Atkinson	J. P. de Lima
H. Benest	P. V. Luke, C.I.E.
W. E. Burnand	H. Marryat
F. C. E. Burnett	Professor T. Mather
R. B. Burrowes	C. H. Merz
P. Hunter Brown	C. Mittelhausen
J. Caldwell	The Osram Lamp Works, Ltd.
C. B. Clay	H. Parry
J. D. Dallas	F. Pooley
Messrs. Dick Kerr & Co., Ltd.	H. A. Ratcliff
The Diesel Engine Users' Association	F. C. Raphael
M. G. Drake	W. R. Rawlings
K. Edgcombe	J. H. Rider
A. R. Everest	D. E. Roberts
Messrs. Evershed & Vignoles	A. G. Seaman
Sir John Gavey, C.B.	H. C. Silver
E. Garcke	S. Simpson
B. B. Granger	D. Sinclair
R. Hammond	H. Skelton
W. V. Haslam	J. B. Smith
F. B. O. Hawes	R. T. Smith
W. J. Head	Sir John Snell
K. Hedges	C. P. Sparks
D. Henriques	A. A. C. Swinton
F. Higgins	E. Brough Taylor
The Incorporated Municipal Electrical Association	W. Thom
The Institute of Railway Signal Engineers	C. Turnbull
B. M. Jenkin	The Twenty-five Club
R. J. Kaula	C. O. Varley
J. H. R. Kemnal	E. O. Walker, C.I.E.
J. W. Kempster	T. C. T. Walrond
W. E. Lane	T. S. Watney
	A. Williamson
	W. B. Woodhouse
	J. H. Woodward

Legacy—Augustus Stroh.

Among the larger donations received during the year were a legacy of £250 from the late Mr. Augustus Stroh and a donation of £105 from Mr. J. H. Rider.

The Committee of Management desire to acknowledge their indebtedness to these and the other donors and subscribers who have supported the Fund, but they venture once more to urge upon the members the pressing need for a more generous support of the Fund. Apart from donations the Committee will be grateful for annual subscriptions even of small amounts.

#### GRANTS.

Seven applications for assistance were received in 1915, and the Committee, after due investigation, made grants in

all the cases. Four grants were made of £25 each, two of £10, and one of £6, a total of £126 for the year.

#### WILDE BENEVOLENT FUND.

The Capital Account stood on the 31st December last at £1,846 4s. 6d., the whole of which is invested and brings in an annual revenue of £55 17s. 0d.

The balance standing to the credit of the Income Account at the end of 1915 was £436 4s. 1d., of which £345 14s. 8d. was invested, and brings in an annual income of £13 10s. 0d.

No grant from this Fund was made during the year.

## INSTITUTION NOTES.

### ELECTRICITY SUPPLY IN GREAT BRITAIN.

The Council have appointed a Committee to consider the suggestions made in Mr. E. T. Williams' recent paper (see page 581) and in the discussion on "The Present Position of Electricity Supply in the United Kingdom" (see page 588). After consultation with the Incorporated Municipal Electrical Association and other similar bodies connected with electricity supply, the Committee will embody their recommendations in a Report to the Council.

### ELECTRICAL TRADES COMMITTEE.

A Committee of the whole Council recently had under consideration certain matters affecting the Electrical Engineering Profession, but shortly before the Committee presented their Report to the Council, the attention of the latter was drawn to an announcement in the Press that the Board of Trade had decided to appoint Committees to consider the position of certain important British industries after the War, especially in relation to international competition, and to report what measures, if any, are necessary or desirable in order to safeguard that position. It was also announced that two Committees had already been appointed for (a) the Iron, Steel, and Engineering Industries, and (b) the Shipping and Ship-building Industries.

It was thereupon decided by the Council that a letter be sent to the Board of Trade urging the appointment of a separate Committee on the above lines for the Electrical Trades, and an announcement appeared in the Press on the 26th April, 1916, to the effect that such a Committee had been appointed by the Board.

The President of the Institution having been recently invited to give evidence before the Electrical Trades Committee, it was resolved by the Council that the following recommendations, based upon the conclusions reached by the above-mentioned Committee of the whole Council, be

submitted by him to the Board of Trade Committee on behalf of the Council:—

- (1) Some combination of British electrical firms, especially with regard to overseas trade, is desirable.
- (2) A Government Tribunal of the most independent character that can be devised to be appointed to control the Electricity Supply Industry of the country, and also to prevent indiscriminate addition or extension of power stations or systems undesirable from the point of view of size, locality, or system.
- (3) In view of the necessity of securing the home market and that none other than British electrical apparatus be purchased in the United Kingdom, a protective tariff to be set up, notwithstanding such benefits as will in any case result from patriotism.
- (4) A permanent Advisory Committee to be appointed to ensure that, as far as possible, raw materials and parts as well as whole apparatus necessary to the trade of the British Empire shall be produced within the Empire.
- (5) (i) British-born Electrical Attachés to help in the Consular service, and (ii) Trade Commissioners (Scientific and Technical Commissioners as suggested by Mr. Pollard Digby, *I.E.E. Journal*, vol. 53, p. 799, 1915), to be appointed.
- (6) British Engineering Standards to be adopted throughout the Empire.
- (7) The use of the Metric System to be made compulsory after a reasonable period; and during this period all trade catalogues to make use of both the British and Metric Systems.
- (8) The Institution to be granted a Charter so as to improve the status and training of electrical engineers.

- (9) A Central Engineering Board, consisting of representatives nominated by all the important Institutions, to be established whom all engineers (other than mechanics) would be required to satisfy as to the sufficiency of their technical training and general education before they could be recognized as proficient, so as to ensure that every engineer shall qualify for his profession in the same manner as a doctor or solicitor.
- (10) Closer co-operation of manufacturers and other employers of electrical engineers with the technical colleges is desirable to ensure that students are trained to meet the future needs of the Industry.

#### LOCAL HONORARY SECRETARY AND TREASURER ABROAD.

Mr. J. E. Donoghue has been appointed by the Council to be Local Honorary Secretary and Treasurer for New South Wales.

#### AUDITORS OF THE INSTITUTION.

At the Annual General Meeting held on the 11th May, 1916, Mr. Sidney Sharp was re-elected Honorary Auditor of the Institution, and in accordance with the resolution passed at that meeting (see page 670) the Council have appointed Messrs. Allen, Attfield and Co. to be Auditors of the Institution, to fill the vacancy caused by the retirement of Mr. H. Alabaster, Honorary Auditor since 1906.

#### ENEMY MEMBERS.

With reference to the clause recently added (see page 671) to Article 41 of the Articles of Association, the Council have in preparation a list of those who will cease to be members of the Institution under the new clause, and will publish it as soon as possible.

#### ROLL OF HONOUR.

##### (THIRD LIST.)\*

<i>Killed in Action.</i>			
Alderson, Lieutenant A. R.	Royal Engineers	Associate Member	
Corke, 2nd Lieut. H. W.	Gloucestershire Regt.	Student	
Dyke, Lieutenant G. B.	Royal Garrison Artillery	Associate Member	
Eagle, Lieutenant F. W.	North Midland Divisional R.E.	Student	
<i>Died of Wounds.</i>			
Bates, 2nd Lieut. T. O. H.	Indian Infantry	Associate Member	
Eardley-Wilmot, 2nd Lieut. G. H.	Machine Gun Corps	Graduate	
<i>Died.</i>			
Cheshire, Private J.	Manchester Regt.	Student	
Duesbury, Private T.	Royal Berkshire Regt.	Associate Member	

\* See pages 64 and 447.

#### MILITARY HONOURS AWARDED.

##### (THIRD LIST.)\*

##### Companion of the Bath.

Sankey, Captain H. R.	Royal Engineers	Member
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##### Distinguished Service Order.

Colinus, Captain D. S.	Royal Engineers	Associate Member
Mousley, Major J. H.	East Lancashire R.E.	Associate Member

##### Military Cross.

Anderson, Lieutenant S. G.	Royal Engineers	Student
Challoner, Lieutenant T.	Glamorgan (Fortress) R.E.	Associate Member

"For consistent good work previous to an attack. He went out twice and made reconnaissances under heavy shell fire."—*London Gazette*, 16 May, 1916.

Denison, Lieutenant H. A.	King's Royal Rifle Corps	Student
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"For conspicuous gallantry on several occasions, notably when he attacked a strong enemy patrol with five men, and after inflicting loss on them with bombs, withdrew without casualties under very difficult circumstances."—*London Gazette*, 16 May, 1916.

Ferranti, Lieutenant B. Z. de	Royal Garrison Artillery	Student
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Marvin, Lieutenant E. M.	Royal Engineers	Associate Member
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"For conspicuous gallantry. He went out and rescued a severely wounded man of a working party, carrying him on his back some hundred yards in bright moonlight under heavy machine-gun and rifle fire."—*London Gazette*, 31 May, 1916.

Smith, Major T. V.	Royal Flying Corps	Associate Member
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Sparks, Captain H. C.	London Scottish	Member
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Wayne-Morgan, J.	Glamorgan (Fortress) R.E.	Major
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##### Distinguished Conduct Medal.

Colston, Sergeant C. B.	Royal Engineers	Student
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"For consistent good work and devotion to duty."—*London Gazette*, 21 June, 1916.

Vick, Sapper E. H.	East Lancashire R.E.	Student
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"For conspicuous gallantry when repairing telephone wires under heavy fire."—*London Gazette*, 21 June, 1916.

##### Military Medal.

Burrage, 2nd Corp. C. J.	Royal Engineers	Student
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Legion of Honour (Croix de Commandeur).		
Seligmann-Lui, Colonel G. P.	French Military Telegraphs	Member

Legion of Honour (Croix d'officier).		
Dumaresq, Brevet Lieut.-Col. A. H.	Royal Engineers	Member

##### Mentioned in Dispatches.

Stace, Captain R.E.	Royal Engineers	Associate Member
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\* See pages 306 and 518.

## MEMBERS ON MILITARY SERVICE.

## (EIGHTH LIST.)\*

MEMBERS.		
Name	Corps, &c.	Rank.
Cobbe, G. Van	Canadian Infantry	Lieutenant
Dobson, J. H.	South African Pioneer Corps	Major
ASSOCIATE MEMBERS.		
Alexander, R.D.T.	London Scottish	Major
Birrell, T. H.	Glamorgan (Fortress) R.E.	2nd Lieut.
Briggs, J. C.	Leicestershire Regt.	Captain
Burgess, L. F.	Australian Imperial Force	
Butcher, J. D.	Singapore R.E. Volunteers	Sapper
Clarke, W. G.	Royal Engineers	Captain
Cockshott, E. H.	Royal Naval Air Service	Lieutenant
Coke, N. R.	Canadian Infantry	Lieutenant
Crowther, J. P.	London Electrical Engineers	Sapper
	R.E.	
de Wardt, J. C.	Kent (Fortress) R.E.	Lieutenant
Dove, W. E.	Royal Garrison Artillery	2nd Lieut.
Dyer, C. F.	Royal Navy	Elec.
		Artificer
Eastman, H. A.	Royal Engineers	Cadet
Fox, C. H.	Royal Naval Reserve	Warrant
		Eng.
Graves, E.	South Lancashire Regt.	
Hart, W. H.	Army Service Corps	Lieutenant
Jackson, D.	London Electrical Engineers	Sapper
	R.E.	
Jeffries, T. W.	London Electrical Engineers	Sapper
	R.E.	
Kapp, R. O.	Artists Rifles O.T.C.	Cadet
Kingsbury, H.	Royal Garrison Artillery	2nd Lieut.
Lewenz, H. I.	Staff for R.E. Services	Lieutenant
Martin, P. M.	London Electrical Engineers	Sapper
	R.E.	
Menzies, F. A.	Reserve of Officers, Indian Army	2nd Lieut.
Nimmo, H. W.	London Electrical Engineers	Sapper
	R.E.	
Page, G. W. P.	London Electrical Engineers	Sapper
	R.E.	
Partington, G. A.	London Electrical Engineers	Corporal
	R.E.	
Peel, M. L.	Cape Fortress Engineers	Staff-Sergt.
Scampton, G. O.	London Electrical Engineers	Sapper
	R.E.	
Shumaker, F. N.	Royal Flying Corps	Captain
Singleton, C.	Royal Engineers	2nd Lieut.
Stancombe, T. R.	Army Ordnance Dept.	Lieutenant
Stephens, F. C.	South African Overseas Force	
Thrupp, F. E. M.	East Lancashire R.E.	2nd Lieut.
White, E. S.	London Electrical Engineers	Sapper
	R.E.	
Williams, G. B.	London Signal Service, R.E.	Major
Winter, J. L.	City of Edinburgh (Fortress) R.E.	2nd Lieut.
ASSOCIATES.		
Heritage, F. C.	London Electrical Engineers	Lance-Corpl.
	R.E.	
Nash, E. A.	Artists Rifles O.T.C.	Cadet
Pilson, C. A.	Royal Naval Air Service	Air Mechanic

Name.	Corps, &c.	Rank.
Beamish, F. N. H.	Royal Warwickshire Regt.	2nd Lieut.
Bolton, E. S.	London Electrical Engineers	Sapper
	R.E.	
Bond, H.	Royal Field Artillery	Cadet
Chandler, C. K.	R.N.V.R.	Sub-Lieut.
Drummond, T.	New Zealand Engineers	Qmr. Sergt.
Kirkpatrick, K. J.	Artists Rifles O.T.C.	Cadet
Smiles, C. A.	R.N.V.R.	Sub-Lieut.

STUDENTS.		
Barton, G. E.	Cheshire Regt.	2nd Lieut.
Colston, C. B.	Royal Engineers	2nd Lieut.
Davidson, K.	Royal Navy	Elec.
		Artificer
French, E. A. H.	London Electrical Engineers	Sapper
	R.E.	
Gibson, H. C.	London Electrical Engineers	Sapper
	R.E.	
Higby, H. V.	Indian Infantry	2nd Lieut.
Lee, H. B.	Royal Engineers	2nd Lieut.
McCourt, D.	Royal Engineers	Sapper
Nicoll, D. E.	Royal Flying Corps	2nd Lieut.
Rankin, D. A.	London Electrical Engineers	Sapper
	R.E.	
Ravn, W. A.	Inns of Court O.T.C.	Private
Whitaker, G. B.	Royal Engineers	Lieutenant

## PROMOTIONS, TRANSFERS, ETC., OF MEMBERS ON MILITARY SERVICE.

## (FOURTH LIST.)\*

MEMBERS.		
Name.	Corps, &c.	Rank.
Bridges, W.	London Brigade, R.F.A.	Lieut.-Col.
Dumaresq, A. H.	Royal Engineers	Lieut.-Col.
Haslam, S. B.	Rifle Brigade	Captain
Marshall, W. H. U.	Dorset (Fortress) R.E.	Captain
Morcom, R. K.	Royal Engineers	Captain
†Stuart, A. M., C.B.	Director of Works	Maj.-Gen.
ASSOCIATE MEMBERS.		
Amberton, R.	Royal Fusiliers	Captain
Arnold, C. L.	Royal Garrison Artillery	Lieutenant
Barker, J. S., M.V.O.	Royal Engineers	Major
Carly, S. W.	Army Service Corps	Lieutenant
Challoner, T.	Glamorgan (Fortress) R.E.	Lieutenant
Dalglish, I. S.	London Electrical Engineers	Lieutenant
	R.E.	
Eadie, J. C.	Royal Navy	Eng. Sub.
		Lieut.
Empson, A. W.	Royal Flying Corps	2nd Lieut.
Gardiner, B. C.	Royal Marine Light Infantry	Major
Gill, V. W.	Royal Fusiliers	2nd Lieut.
Harris, L. V.	Royal Engineers	2nd Lieut.
Hodson, W.	Royal Sussex Regt.	Lance-Corpl.
Hollings, G. A.	Royal Engineers	2nd Lieut.
Hurlbutt, D. G.	Indian Infantry	2nd Lieut.
Langdon, W. C. C.	Royal Garrison Artillery	Lieutenant
Long, R. F.	Royal Field Artillery	Lieutenant
Mann, F. H.	Divisional Engineers, R.N.D.	Corporal
Marvin, E. M.	Royal Engineers	Lieutenant
Porter, A. R. Z.	London Electrical Engineers	Lieutenant
	R.E.	

\* See vol. 53, pp. 196, 329, 388, and 857; and vol. 54, pp. 121, 405, and 518.

\* See pages 157, 494, and 579.

For service in the field

## ASSOCIATE MEMBERS—continued.

<i>Name.</i>	<i>Corps, etc.</i>	<i>Rank.</i>
Pratt, L. H.	Royal Engineers	2nd Lieut.
Puttick, A. W.	Royal West Kent Regt.	Lieutenant
Redfern, W. D.	East Lancashire R.A.M.C.	Lance-Corpl.
Roberts, G. B.	Royal Engineers	Lieut.-Col.
Shaw, R.	City of Edinburgh (Fortress) R.E.	2nd Lieut.
Smith, T. V.	Royal Flying Corps	Major
Stanier, H. D.	Royal Engineers	Lieutenant
Vaudrey, R. H. N.	Royal Engineers	Lieutenant
ASSOCIATES.		
McDougall, P. W.	R.N.V.R.	Lieutenant
Pilkington, S.	Leicestershire Regt.	Captain
Vickerman, M. H.	Army Service Corps	Lieutenant
GRADUATES.		
Lintott, A. L.	Machine Gun Corps	Major
Mansell, L. T. G.	Royal Flying Corps	Lieutenant
STUDENTS.		
Aylmer, J.	Royal Fusiliers	Captain
Burrage, C. J.	Royal Engineers	2nd Corpl.
Clark, R. M.	Royal Engineers	2nd Lieut.
Devonald, N.	Royal Garrison Artillery	Lieutenant
Dunham, D.	South Lancashire Regt.	2nd Lieut.
Dunn, R. C.	Army Ordnance Corps	Private
Floyd, L. G.	London Electrical Engineers, R.E.	Sergeant
Hartley, J. B.	Royal Garrison Artillery	2nd Lieut.
Hitch, A. T.	Bedfordshire Regt.	Captain
Mittell, B. E. G.	Royal Engineers	2nd Lieut.
Priestley, A.	Divisional Engineers, R.N.D.	Corporal
Rawlings, W. J.	London Electrical Engineers, R.E.	Lieutenant
Rawson, S. M.	Royal Fusiliers	Lieutenant
Spencer, W. G.	Royal Engineers	2nd Lieut.
Stone, H. J.	Royal Engineers	2nd Lieut.
Tipping, G. O.	Devon (Fortress) R.E.	Lieutenant
Tuppen, H. R.	Army Service Corps	Captain

## ELECTRICAL ENGINEERING TEXTBOOKS FOR BRITISH PRISONERS OF WAR.

The Secretary is informed that the Board of Education will be glad to receive from members of the Institution gifts of standard textbooks on electrical engineering subjects for distribution among British prisoners of war interned abroad, from whom several requests for books of this kind have been received. All parcels of books and communications on the subject should be addressed to A. T. Davies, Esq., Welsh Department, Board of Education, Whitehall, London, S.W.

## REDUCTION IN CONSUMPTION OF COAL FOR LIGHTING PURPOSES.

A meeting of electricity supply engineers was held in the Lecture Theatre of the Institution on the 8th May, 1916, to consider a letter dispatched by the Board of Trade to gas and electric lighting undertakings, requesting them to inform their consumers that the consumption of coal for lighting purposes must be reduced by 10 per cent. After the views of those present had been ascertained, it was agreed that a letter embodying these views should be addressed by the President to the Board of Trade, and this was accordingly done on the following day.

## ACCESSIONS TO THE REFERENCE LIBRARY.

- BENNETT COLLEGE, THE. "Electricity." Edited by the professors of the Bennett College. vol. 4, Power stations. [By] W. N. Y. King. 1a 8vo. 250 pp. *Sheffield*, [1916]
- CANADA. DEPT. OF MINES; MINES BRANCH. Summary report for the year ending Dec. 31, 1914. 8vo. 242 pp. *Ottawa*, 1915
- CENTRAL TRANSLATIONS INSTITUTE, LTD. Russian equivalent tables. Prepared from official figures. folded 8vo. [*London*, 1915]
- CLAPP, F. G., and others. Petroleum and natural gas resources of Canada. [Canada, Dept. of Mines, Mines Branch]. 2 vol. 8vo. *Ottawa*, 1914-15  
1, Technology and exploitation. [With map].  
2, Description of occurrences.
- COLEMAN, Lt.-Col. T. E. The civil engineers' cost book. 2nd ed. sm. 8vo. 401 pp. *London*, 1916
- CROSS, C. F., and BEVAN, E. J. A text-book of paper-making. 4th ed. Containing additional matter, and in part re-written, with collaboration of J. F. Briggs. 8vo. 517 pp. *London*, 1916
- FLEMING, J. A. An elementary manual of radiotelegraphy and radiotelephony for students and operators. 3rd ed. 8vo. 374 pp. *London*, 1916
- HAMMOND ELECTRIC LIGHT AND POWER SUPPLY COMPANY, LIMITED. Price list of electrical machinery. 8vo. 15 pp. [*London*, 1884]
- HAY, A. An introductory course of continuous current engineering. 2nd ed. 8vo. 372 pp. *London*, 1916
- KEMPE, H. R. Alternating currents. Their elements explained, and their calculation effected without the use of hyperbolic functions. sm. 8vo. 91 pp. *London*, 1916
- LANINO, P. Per la nazionalizzazione delle nostre industrie. Conferenza, Collegio Nazionale degli Ingegneri Ferroviari Italiani, 9 Febbraio, 1916. [Supplemento alla "Rivista Tecnica delle Ferrovie Italiane," 15 Febbraio, 1916, n. 2]. sm. folio. 95 pp. [*Roma*, 1916]
- MARTIN, M. J. Wireless transmission of photographs. 8vo. 129 pp. *London*, 1916
- MAUDUIT, A. Électrotechnique appliquée. Cours professé à l'Institut Électrotechnique de Nancy. Avec une préface de A. Blondel. 8vo. 859 pp. *Paris*, 1904
- MORRIS, J. T., ELLIS, R.M., and SROUVE, F. The design of a continuously adjustable resistance. [Reprinted from "The Electrician," June 26, 1908]. 8vo. 11 pp. [*London*, 1908]
- PETERS, O. S. Protection of life and property against lightning. [United States, Technologic Papers of the Bureau of Standards, no. 56]. 8vo. 127 pp. *Washington*, 1915
- PIDDUCK, F. B. A treatise on electricity. 8vo. 672 pp. *Cambridge*, 1916
- ROSA, E. B., and McCOLLUM, B. Electrolysis and its mitigation. [United States, Technologic Papers of the Bureau of Standards, no. 52]. 8vo. 143 pp. *Washington*, 1915
- TAYLOR, F. H. Private house electric lighting. 6th ed. sm. 8vo. 142 pp. *London*, [1915]
- ZENNECK, J. Wireless telegraphy. Translated by A. E. Seelig. 8vo. 463 pp. *New York*, 1915

## OBITUARY NOTICES.

**RICHARD EVERARD WEBSTER, VISCOUNT ALVERSTONE, G.C.M.G.**, born on the 22nd December, 1842, was the second son of Thomas Webster, one of the founders of the Society of Arts. He was educated at King's College, London, at Charterhouse, and at Trinity College, Cambridge. In 1868 he was called to the Bar and soon obtained a large practice, devoting himself more particularly to railway work and patents. In 1885 he entered Parliament as member for Launceston. This town shortly afterwards ceasing to be a Parliamentary borough, he successfully contested the Isle of Wight and sat for that constituency for 15 years. He was made Attorney-General soon after entering Parliament and held that office from 1885 to 1892 and from 1895 to 1900. In the last-mentioned year he was appointed Master of the Rolls, becoming in October of the same year Lord Chief Justice of England. During his Parliamentary career and whilst on the Bench he was engaged in many important cases, among others, the Behring Sea Arbitration in 1893, the Transvaal raid of 1896, the Venezuela dispute in 1899, and the arbitration between the United States and Great Britain to determine the boundaries of Alaska. In recent years he took a prominent part in the Court of Criminal Appeal, over which he usually presided. In 1899 he was made a baronet, and in June 1900 he was raised to the peerage, being afterwards created a Viscount on his retirement in 1913. He died on the 15th December, 1915, at Cranleigh, Surrey. He was elected a Member of the Institution in 1891.

**BRACKENBURY BAYLY** died on the 4th August, 1914, at the age of 59. He first became connected with the telegraph service in 1871, and was a few years later appointed an inspector of the Government Telegraphs, Cape Town, subsequently becoming Surveyor and District Engineer of the Western District, Cape Colony. He constructed several important telegraph lines in Cape Colony, Natal, and Transvaal, and eventually became Chief Technical Officer and Assistant Engineer in the G.P.O., Cape Town. He was elected an Associate of the Institution in 1877 and a Member in 1886. He served on the Committee of the Cape Town Local Centre in 1900, and was Chairman of that Local Centre in 1902-3.

**WILLIAM CASSON** was born at Portmadoc on the 18th August, 1873. He was educated at Ruthin Grammar School and afterwards at the Central Technical College, London. From 1893 to 1895 he was employed with the Electrical Installation Company; after which he was for four years at the Elswick works of Armstrong, Whitworth and Company in the electrical design department. In 1899 he joined the staff of Mr. H. F. Parshall, where he was chiefly concerned with the planning and construction of the London United Tramways, and with the electrification of the District and Metropolitan Railways, more particularly in connection with the arbitration between the District and Metropolitan Railways in regard to the form of traction to be adopted on the Inner Circle. In 1895 he was appointed sub-station engineer on the Underground Railways, and remained in charge until 1907 when he

joined the staff of the Central London Railway as chief assistant engineer. When the operation of the Central London Railway was taken over by the Underground Electric Railways Company he was appointed chief assistant to the mechanical engineer on the construction of new rolling stock. He was an enthusiastic Volunteer for several years, and reached the rank of Captain of the 7th Battalion of the London Regiment in 1903. During attacking operations in France on the 25th September, 1915, he was ordered to lead the Battalion to a position on the extreme right flank, which was a dangerous but highly important position. This he accomplished with a skill which was the admiration of all who witnessed it, but he was shot by a sniper as he stood on the parapet rallying his men. He was elected an Associate Member of the Institution in 1901 and a Member in 1912.

**HENRY CROOKES** died on the 28th August, 1915, in his fifty-seventh year. He was the eldest son of Sir William Crookes, O.M., F.R.S. From 1878 he was for two years in Paris studying chemistry, first at large chemical works at Clichy-la-Carenne, and later at the Ecole de Medicine under the late Professor Wurtz. Returning to London he entered the Royal College of Science and took the degree of Associate. From 1887 to 1890 he filled appointments as chemist, assayer, and manager to various mines in South Africa, and returned to England after three years in the Transvaal and Bechuanaland. For 14 years he was chief assistant in the Laboratories of the London Water Companies, and afterwards practised as an analyst and metallurgist in conjunction with Sir William Crookes and Sir James Dewar, devoting most of his time to bacteriology. In this branch of his work he had great experience, being one of the first to make it a special study. He also made researches on the action of radium on bacteria, and had a most interesting exhibit at the Royal Society in 1904. Various cultures of bacteria were exposed to the action of 10 milligrams of radium through a mica screen at about 1 inch distance from the surface of the plate. After having been subjected to the action of the radium emanations, electrons in these case, the plates were incubated. In every case it was found that the microbes had been killed where they had been exposed to the radium, so that on incubation a bare space was left free from bacterial growth opposite the point where the radium had been placed. Later he used bacillus phosphorescens for his experiments on the action of different metals on bacteria, and once more exhibited some interesting results at the Royal Society in 1911. It was his research in this direction that led him to the study of metallic and non-metallic colloids, which eventually developed into the products known as "Crookes Colloids." He was elected an Associate of the Institution in 1883 and a Member in 1886. He married in 1883 Nina, the second daughter of the late Mr. C. E. P. D. Spagnoletti, a Past President of the Institution.

**ERNEST DANVERS** died on the 2nd July, 1915, at the age of 51. He was born in Paddington, London, in 1863 and went to Argentina in 1888. In 1890 he became Secre-

tary to Mr. P. Clarke in the Engineers' Department of the Buenos Aires and Rosario Railway. From 1892 until his death he was connected with the *Review of the River Plate*, for the last 15 years being editor, director, and proprietor of that Journal. He also devoted considerable attention to engineering and for many years was electrical adviser to several fire insurance companies in Buenos Aires. He was elected an Associate of the Institution in 1885, and a Member in 1888, and he served as Honorary Local Secretary and Treasurer for Argentina from 1900 until his death.

ROBERT ARTHUR DAWBARN, who died on the 6th March, 1916, was born at March, Cambridgeshire, on the 30th November, 1860. He was educated at Tettenhall College, Staffordshire, and whilst serving his pupilage with Messrs. Neilson and Company (later Neilson, Reid and Company) also attended engineering classes at Anderson's College (now the West of Scotland Technical Institute). In 1881 he became assistant engineer to the British Electric Light Company, and three years later received an appointment on Mr. J. S. Raworth's staff in connection with ship lighting. From 1885 to 1887 he was with Messrs. Siemens Brothers and Company. In the latter year he went to the Brush Company, becoming a year later chief assistant engineer to Mr. Raworth, who was at that time superintending engineering to the Company. During the greater part of the time that he remained with this Company he had charge of their estimating department and was responsible for many of the electric lighting schemes designed and carried out at that time for municipalities and electric light and power companies. In 1899 he visited Australia on behalf of the Brush Company in order to amalgamate the Melbourne electric lighting companies, and on his return he was appointed superintending engineer, and also had charge of the traction department. A year later, in 1900, he resigned his position with the Brush Company in order to devote his attention to consulting work, entering into partnership with Mr. W. M. Mordey. In connection with this consulting practice he paid frequent visits abroad, among others to South America and South Africa. He was elected an Associate of the Institution in 1888 and a Member in 1894. He was also a Member of the Institution of Civil Engineers.

HENRY CORNELIUS DONOVAN was born at Wandsworth on the 13th July, 1842. After being educated at proprietary schools and the City of London School, he commenced his career by taking up a clerkship in a wholesale stationery firm, but soon tired of clerical work and sought more congenial employment. This he found, in 1862, in the old Electric and International Telegraph Company, long since absorbed, in common with all similar enterprises, by the Post Office. In 1864, soon after the formation of the Telegraph Construction and Maintenance Company by the amalgamation of Messrs. Glass, Elliot and Company and the Gutta Percha Company, he joined the electrical staff of that Company at East Greenwich. In 1866 he left that Company and entered the service of the Silvertown Company. Subsequently he left England with an expedition organized for the laying of cables in the West Indies. A severe epidemic of yellow fever broke out

on the vessel on her arrival in the West Indies, and many fatalities occurred, retarding the operations. Mr. Donovan escaped infection himself, and earned high commendation by the fearlessness and assiduous care he displayed in nursing those members of the expeditionary staff who were attacked by the disease. In the autumn of 1868 he rejoined the Telegraph Construction and Maintenance Company, in whose service he remained from that date until his retirement from active work in 1908, having been prominently associated throughout this period with the manufacture and submersion of the numerous important submarine cables undertaken by the Company. He was one of the few surviving electricians engaged on the laying of the 1865 and 1866 Atlantic cables by the s.s. *Great Eastern*, and was also one of the oldest members of the Institution, of which he was elected an Associate in 1872 and a Member in 1874. Although of a retiring disposition, he possessed marked originality of character, together with qualities which endeared him to those who knew him and appreciated his worth.

H. C.

T. H. W. S.

AUGUSTUS EDEN was born on the 28th November, 1842. He started life in the Electric Telegraph Company on the operative side, and joined the Engineering Department of the Post Office in 1884 as a technical officer. Although he had a good working scientific groundwork and a sound knowledge of electrical engineering principles, his real strength—that which made his services invaluable to the Department—was his faculty for seeing the true inwardness of every practical detail. In handling problems of high-speed Wheatstone working or dealing with the occult intricacies of telegraph repeater working, he was unexcelled and unexcelled. By a strange irony the two things which should by all ordinary expectation have proved his lasting monument, scarcely survived his official life. The battery-testing instrument, the conception of which was due to him, was an ingenious device of two rheostats and a system of shunts which, in conjunction with a galvanometer, provided for the direct reading of the voltage and the resistance of any known number of bichromate, Leclanché, or Daniell cells. The introduction, however, of a single (duplicate) set of secondary cells for working the whole of the circuits in an office necessarily put the battery-testing instrument out of commission. His morning-test system also was another happy inspiration. Every important telegraph circuit was tested every morning in order to ascertain its condition before the commencement of the day's work. His conception was to use a differentially wound galvanometer and to test the circuits in pairs, thus reducing the number of tests to half; and to eliminate discrepancies due to differing "constants" at different offices by making the complete test at one end of the two looped circuits. The whole scheme was perfected and developed in a most ingenious and thorough manner. Another invention was the "skew zero" tangent galvanometer, a device whereby the open portion of the tangent scale became available for the higher readings. But no one uses a tangent galvanometer now! These and many other ideas were the results of his faculty for observing things that, as he said, "no fellow could understand." Anyone could easily explain them mathematically when he had discovered them; but the

instinct that led him to correct results was all his own. In 1902 he refused promotion in order that he might not have to change to duties for which he (as well as those of his colleagues who knew him best and regarded him most) felt himself to be little suited; but in 1904, seeing no other channel of progress, he accepted charge of a district as superintending engineer. He transferred to Edinburgh in charge of East Scotland in 1905, and retired in 1907. His earlier experience as a Territorial artillery officer enabled him to do good work in training young officers during the earlier days of the present war—work which probably led to a breakdown of his health early in 1915. His death occurred on the 8th July, 1915. He was elected an Associate Member of the Institution in 1874 and a Member in 1891, and he served on the Council in 1890.

A. J. S.

ERIC GERARD was born in Liège in 1856 and graduated at the University of Liège in 1873 with the degrees of *Ingénieur Honoraire des Mines* and *Ingénieur des Arts et Manufactures*. After completing his studies at the Belgian Government School of Posts and Telegraphs, he was appointed electrical engineer to the Belgian State Telegraphs. In 1881 he served as Joint Secretary with M. Mascart to the Electrical Congress in Paris. In 1883 he was appointed Principal of the newly established electrical college which had been founded and endowed by the late Senator Montefiore as an adjunct to the University of Liège. This was one of the first colleges of its kind. He was the author of "*Elements d'Électrotechnique*" and of "*Leçons sur l'Électricité*," many editions of which have appeared and which have also been translated into English. He also published "*Mesures Électriques*" and "*Traction Électrique*," and just before his death was working on an entirely revised edition of his works. He collaborated with his chief assistant, M. de Bast, in writing "*Exercices et Projets d'Électrotechnique*." He was President of the Belgian Official Board of Electricity and member for Belgium of the International Electrotechnical Commission, was Officer of the Order of Leopold, and also held many other Orders. He presided at one of the early meetings of the International Electrotechnical Commission held at Brussels in 1910, and it was he who arranged for the delegates to be conducted through the Brussels Exhibition and who conducted them to Liège, where they were received by members of the Montefiore Electrotechnical College. Professor Gerard took a keen interest in the nomenclature of electrical units and was present both in Paris and Cologne at the meetings of delegates of the Commission when these matters were discussed. He was called in to advise in connection with many engineering undertakings, and his opinion on these, both from a scientific as well as from a commercial side, was highly esteemed in the most influential circles. In his later years Professor Gerard took a great interest in the development of the Belgian Congo, having been appointed by King Leopold II to investigate the possibility of electrically treating the copper ores of the Katanga. He was one of the directors and founders of the *Société Géomine*, the Chairman of which was the late M. A. Greiner, the general manager of the Cockerill Works of Seraing, near Liège. It was due to the efforts of this company that the large coal deposits in the Congo were discovered and worked, and it was also

through its efforts that the very valuable tin deposits in that region were brought to light. Professor Gerard foresaw, as far back as 1890, the great future of electricity in connection with traction and also in metallurgy. In addition to his ability as a professor, he had great personal charm and an attractive disposition which greatly attached to him all those who came under his influence. He combined with a very scientific mind, very sound commercial ideas, and was always quick to grasp the value of new ideas and discoveries; thus, he was the first to bring to the notice of Belgian doctors the great value of X-rays, and was the first to experiment with wireless telegraphy in Belgium. He has left his mark on the electrical and engineering world and there is no country where engineers who have been trained by him are not to be found occupying important and influential positions. He will be deeply mourned by all those who had the privilege of meeting him, by his friends, and by the wide circle of his students. He was elected a Foreign Member of the Institution in 1883, a Member in 1911, and an Honorary Member in 1914.

P. D.

ROBERT HAMMOND, Honorary Treasurer of the Institution, died on the 5th August, 1915. A memoir of him in these pages is at once a grateful and an embarrassing task. He was so intensely human, his sympathies and activities were so diverse, that no honest admirer can help grudging the limits that electrical specialization imposes. If the path is here and there transgressed, the fault must be counted as objective rather than subjective.

Robert Hammond was born at Waltham Cross, Hertfordshire, on the 19th January, 1850, and was educated at Nunhead Grammar School. Soon after leaving school he reached the counting house of some cloth merchants in St. Paul's Churchyard. Here he became one of the chief clerks in the foreign department, but the hide-bound routine of this occupation quickly disgusted him, he threw it off and looked about him for something more worthy of his abilities. These were both great and various; more than one of the persons associated with him have wondered that the electrical field should have contained him. Men far less richly endowed have made names for themselves in the nation's general history. This failure is less due, perhaps, to genuine want of concentration than to the impatience of a highly sanguine temperament. Such strongly marked characters are so complex as at times to appear inconsistent. His capacity for real, hard, slogging work was prodigious, he was never seen idle. Yet towards slavish routine which held no exultation promise his attitude was almost that of the truant who, condemned to a holiday task, catches the glint of sunshine on the apple trees outside. The electrical industry is indebted to this knight-errant ambition. But it was also this consciousness of the open window that drew him abroad; his spirit of adventure equipped him as a rancher, and at one time he came into collision with one of the most redoubtable outlaws in the United States. That, however, is one of many romantic episodes outside the present picture. It is more to the purpose that he went to Bilbao in connection with the iron-ore trade, and thence we can easily trace the connection with Middlesbrough, rolling mills, and the electric lighting thereof. It should here be noted that he was related to the Dormans

of Dorman, Long and Company. It was therefore natural that he should spend several years in the Cleveland district, where he was well known as a partner in the firm of Hammond, Kyle and Company, Middlesbrough-on-Tees, about the year 1876. As an iron merchant he amassed a certain fortune, but this was drawn under by the crash in South American securities which brought to grief the Spanish financial house of Murrieta.

It was extremely fortunate for the tender electrical plant of those days that his eye so clearly visioned its growth and fruits; he became one of the greatest of electrical pioneers. What first roused his enthusiasm was the display of Jablochkoff candles on the Thames Embankment in 1878.

To begin by summarizing briefly some of the feats that he accomplished:—

In the early eighties he had already toured the country giving lectures. He founded an electrical engineering college—now Faraday House. His house at Highgate was the first one in Europe electrically lighted throughout. He wrote a book on electric lighting, the first one of its kind. He was one of the leaders of the group who set out to get the defects of the faulty 1882 Act remedied. These efforts produced the amending Act of 1888 in which the compulsory purchase period was raised to 42 years. Setting aside all the progress thus promoted, he was himself personally responsible from first to last for the laying out of more than three millions sterling on electrical plant and works; he lighted more than 50 factories, hotels and rolling mills; he established between 30 and 40 electric light and power undertakings for municipalities and companies; he contributed greatly to the standardizing of conditions of engineering contracts and to the method of conducting steam-consumption tests in power stations; he instituted a weekly criticism of electrical generating costs, and by this and other means was a powerful instrument in lowering the cost of electricity; he gave evidence before Parliamentary Committees in 14 important Power Bills; he was concerned with 21 arbitration cases; he established one of the present electrotechnical journals, and even then his energies overflowed into other electrical affairs which may be mentioned later. In these electrical enterprises, especially the earlier ones, Robert Hammond was the life and soul of all that was going on. One imagines him as scarcely sleeping in a bed at all, but more often in the train. There were electrical exhibitions in different places, as at Bradford, where Mr. Albert Gay was in charge. Then, too, at the Electric Light Exhibition at the Crystal Palace the Hammond Electric Light and Power Supply Company was duly represented.

If electrical work occupied most of his business hours, in his play-time he still found leisure to offer himself as a Liberal Parliamentary candidate for Sheffield. It was here he contested the Hallam division against Mr. Stuart Wortley in 1889, and in his address to the electors he appealed to working men as one "knowing what the hardships of life might be, having gone to the City with his five thick slices of bread and butter for his lunch, and having generally to work his way up." He gave Free Trade lectures, he wrote a pamphlet on it, he was the leading spirit of a church choir, he debated on social problems. Later on he was an ardent golfer; he was a finished Bridge player and wrote two books on the

subject—also an earlier book on Whist—he learned to speak French, Spanish, Italian, and German. Above all, he was a gifted speaker of English. At an early age he took a prize at a debating society for impromptu oratory, and how many of us have richly enjoyed his after-dinner speeches! Some of them were masterpieces, at times they scintillated with humour, it was seldom that he sat down without a loud volley of applause. As an advocate of electro-political causes he was inimitable, whether in the witness box, before a Parliamentary Committee, or elsewhere. Exceedingly quick to catch the flaws of an adversary's pleading, he was equally subtle in constructing the best possible case for his own side. Naturally, he was often put forward as a champion.

Shortly after the completion of his private installation in 1882, he gave a lecture on electric lighting at Highgate. It attracted no little attention and brought him requests from all over the country for similar lectures. This was precisely the sort of thing to appeal to him. He had a travelling van fitted up with a portable lighting equipment and for more than a year spent a great part of his time in lecturing in all parts of the country. All the proceeds of these lectures were applied to charitable purposes. He himself bore all the expenses, and when he brought the effort to a close in 1883 the ledger account in his books showed that he had presented the good cause of infant electricity with well over a thousand sterling. But his primitive essay in electric lighting was two years earlier, in 1880, when he equipped some arc lamps round the blast furnaces of Bernhard Samuelson and Company, Middlesbrough. This led to his undertaking similar work on a larger scale at the works of Bolckow, Vaughan and Company in 1881. For the first time in history it became possible to straighten rails by artificial light. In 1881 also he laid down a 2,000-volt continuous-current generator for the public lighting of Chesterfield; another one, in the same year, was installed for the street lamps at York to honour the British Association meeting. Sir John Lubbock, the President, objected to the plant as a nuisance, Robert Hammond was requested to remove his buzz from the gardens, it disturbed the flow of science. The "central station" was cheerfully buzzing away on another site within 30 hours, the British Association had silent light, though they might have done something better. The Cockermouth incident of 1881 was always one of Robert Hammond's favourite stories. Excursion trains were run in from all parts of Cumberland, the town was *en fête*, municipal dignitaries stood ready on a platform, at the appointed time, to press the magic button and let there be light. In breathless silence, all eyes peered aloft. No light came! An electrician from the Wild West, of scientific claims but bronco associations, had been impressed at the last moment in the absence of the proper assistant. This person decamped, leaving the arcs all coupled up the wrong way, no dynamo brushes, and formidable local debts. This was the sort of thing that Robert Hammond righted and then laughed at. Yet he never forgot a breakdown, he had a passion for system and organization, and this he indulged in his steam-consumption test programmes which were the completest thing of their kind. From the initial comparison of watches to the final carrying off of the meter for calibration, the items must have run into hundreds. Of matters physical he seemed to believe that

every defect on earth could be remedied by analysis, checking, and counterchecking. Though he had made and lost one or two fortunes, he was so sanguine that only a year or two before his death did he concede some grudging acknowledgment that there is a perversity of things which cannot wholly be defeated.

From the offices at 110 Cannon-street, in January 1882, was issued the Hammond Company's prospectus with the heading in large red letters "Brush System of Electric Lighting and Lane Fox Incandescent Lamp." Robert Hammond foresaw many things that have only lately been realized; he not only purposed to distribute power from central stations but also "(5) to supply electricity for the generation of heat." The Anglo-American Brush Electric Light Corporation had not progressed very far before the Hammond Company became associated with them. It was from the Brush Company that Robert Hammond obtained a licence to sell Lane Fox glow lamps. Another document, issued about this time, announced that the Hammond Company were "Sole agents for the Ferranti system of electric lighting." This was a most important epoch. The early association with Dr. S. Z. de Ferranti is well known. In a report dated the 2nd April, 1884, the Hammond Company claimed "Well equipped works in which every form of apparatus connected with electric lighting work can be manufactured" and "special works for the manufacture of incandescent lamps, which are being made by machinery at a reduced cost." A difficulty arose in working the Lane Fox lamp licence, and the "Wright and Mackie" process was adopted in 1883. Mr. James Swinburne superintended this work at Bermondsey. When the Brush Corporation failed to supply dynamos for incandescent lighting, the Hammond Company started exploiting Ferranti dynamos and reported, in May 1883, that the Ferranti Company were completing for them a set "capable of running 5,000 lights, which will, it is expected, be by far the most important dynamo machine which has yet been constructed." The prospect broadened. In 1884 Hammond and Company settled down into offices as iron merchants, general, consulting, and electrical engineers and contractors at 117 Bishopsgate-street Within. Here Robert Hammond's electrical work may be said to have taken a turn which somewhat foreshadowed the future. He was equipping many large works, such as Palmer's shipbuilding yard, Hawthorn's works, Leslie's shipbuilding yard, Charles Cammel's works, Sir Henry Bessemer's, and many others. It is not easy always to assign the exact dates, but these years in the early eighties found either Robert Hammond or "Hammond and Company" busy with the electric lighting of Whiteley's, the First Avenue Hotel, the Ebbw Vale Works, and many other early installations in a long list.

It is one of society's profoundest debts to the pioneer that he faces the music of that early failure which is the forerunner of all success. Robert Hammond had a manly courage. The first effects on the public of the 1882 prospectus were sensational. People of all sorts and conditions, old ladies, clergymen, stockbrokers, tradesmen of all kinds, hastened to apply for shares, and when the day came for exchanging their receipts for scrip certificates a great crowd blocked the gangway of the offices in Cannon-street. The success of this Hammond Company led to the

formation of many others. At the statutory meeting of the Hammond Electric Light and Power Supply Company, quite a multitude of shareholders listened to what had been accomplished, and Mr. Hammond's audience were elated at the prospect of being able to turn on the light without a match. All was enthusiasm. But a time came when the titled Chairman left Robert Hammond himself to face an angry crowd of people who in earlier days had so hung on his words of prophecy. He carried himself superbly in that ordeal, as he ever did in stressed circumstances, and nothing could break the intense calmness with which he faced the mob. The Hammond Company went into liquidation, but eventually every trade creditor received 20s. in the pound, while the shareholders received a small amount against their holdings. Hammond and Company continued on the 1884 basis at 117 Bishopsgate-street Within until 1893. In September of that year Robert Hammond notified the electrical industry that he had decided to cease business as a contractor and to act thenceforward solely as a consulting electrical engineer. From 1894 to 1898 his business was continued at Ormond House, Queen Victoria-street, E.C., and from 1898 until his death he was at 64 Victoria-street, Westminster. It was here, on the 1st January, 1903, that he took his son (now Captain Robert Whitehead Hammond) into partnership and the firm became Robert Hammond and Son. At Bishopsgate-street, Ormond House, and Victoria-street the present writer has often sat opposite to him. "The Chief" had his foibles; one of them was a little disconcerting. He would watch one's calculations upside down, and tot up the column before the operator was anywhere near the result. He was not only clever at mental arithmetic, his memory was well-nigh marvellous, especially for statistics and finance. In this department he was, perhaps, at his best, since it was one of the things on which he really concentrated.

Several "House to House" companies were set afoot by Robert Hammond from 1881 onwards. In the 1889-90 session of Parliament he was responsible for something like 150 applications for Provisional Orders. Of the enterprises which actually took form, one may mention the electric lighting concerns at Brighton (1881), Eastbourne (1882), Hastings (1882), Brompton (1889), and Leeds (1893). To Madrid, in 1890, he gave the first important electric lighting station in Spain, following this by one at Malaga. Other towns that he equipped abroad were Bloemfontein and Port Elizabeth. The 3-phase system of the Dublin Corporation was the first of its kind in these islands; subsequent polyphase designers watched it closely for guidance. Blackpool, Coventry, Newport, Ayr, Gloucester, Canterbury, Hackney, Hornsey, Mansfield, Wakefield are only a few of the municipal electrical undertakings that he established. Meanwhile he found time to take the protagonist's rôle—or, at least, a leading one—in the London Power Bills of 1906, 1907, and 1908. He acted in a dozen others for such districts as South Wales and Lancashire. In the Metropolitan *v.* Marylebone arbitration of 1902 he distinguished himself, but perhaps he was proudest of his retainer in the National Telephone Company *v.* Postmaster-General arbitration in 1911-12.

These things left quite a lot of spare time for such a voracious worker. He composed and read several papers, including an early one at Manchester in 1894 on the

parallel running of alternators, an excellent one before the Institution\* in London on "Cost of generation and distribution of electrical energy," and another on "Depreciation"† read in similar circumstances. He also read at Johannesburg in 1905 an interesting paper on "Power distribution." He enjoyed travel; he visited the United States in early life, also again in 1901 and 1903 to study electrical progress. Having lived in Spain, his work afterwards took him there frequently, as also to France, Italy, Germany, and Constantinople, but he had such marvellous health and recuperative power that no ordeals of travel ever upset him.

There are many things to be remembered in Robert Hammond's honour. We sometimes speak of the Englishman's characteristic inertia against change. Were all Englishmen like Robert Hammond, this country would have recognized and fostered every industrial improvement from babyhood to man's estate. If in public his incisive wit sometimes provided him with a few antagonists, those who knew him privately as "the Chief," or spoke of him not unkindly as "the Old Man," understood that he would never consciously cause pain. He left many deeply indebted to him, and from his funeral last August, more than one of the large group of mourners came away with a face unfit for parade. Bearing in mind Robert Hammond's personality of the last 10 or 20 years, one looks back upon him as a man over-brimming with good humour, with large, frank, blue eyes under somewhat heavy eyebrows, the beard and physique of a Bluff King Hal, the flowing locks of a Rufus, the memory of a Macaulay, and such energy as is seldom given to mortal man. Wherever he went, even in a crowded assembly, he was always a notable figure. The National Liberal Club misses him. On expeditions he was acclaimed as *boute-en-train*. This being an age of meticulous and specialized detail, broad volatile genius such as that of Robert Hammond is hedged round with its limitations. But in 1492 he might have discovered America.

E. S.

Robert Hammond was elected an Associate of the Institution in 1888, and was transferred to the class of Members in 1893. He became a Member of Council in 1899, and served in that capacity until 1902. In the last-mentioned year Professor Ayerton relinquished the position of Honorary Treasurer, and Mr. Hammond was elected in his stead. To this office, which he retained until his death, Mr. Hammond brought all those qualities which have been recorded above. He was unstinting of his time, precise in his preparations, and entered into all the work of his office with an enthusiasm which sometimes ran the risk of overshadowing the painstaking detail. It is as Honorary Treasurer that he will be best remembered, but his active work in the Institution also took other forms. He was a prime mover in the preparation of the Model General Conditions, and he was accustomed to attribute some of the success in the adoption of those Conditions to the experience which he had gained in the dual capacities first as contractor and subsequently as consulting engineer. His contributions to our discussions were frequent, always practical, and sometimes characterized by touches of humour in matter or manner which ensured him a welcome as a speaker. By

the Council and by the Members generally the loss of Robert Hammond will be much deplored. J. E. K.

FREDERICK HERBERT WILLIAM HIGGINS, who was for 40 years chief engineer of the Exchange Telegraph Company and one of the few surviving pioneers of telegraphy, died on the 1st September, 1915, at the age of 66. He began his career with the Electric and International Telegraph Company, and before he was 20 years old had devised the non-inductive shunt which is still in use on repeater circuits. Later, in Mr. R. S. Culley's laboratory he investigated the conditions affecting the rise of current in a submarine cable, and was successful in effecting such an acceleration of the speed of transmission in the Dutch cables as to render unnecessary the provision of a contemplated new cable. He was then appointed Telegraph Engineer to the island of Mauritius. After three years he returned to England and entered the service of the Exchange Telegraph Company. The form of tape machine then used in this country was far from perfect, and he devoted himself with considerable success to its improvement. In 1884 he devised a tape machine working on a single wire. The new invention contained also an improvement in the method of transmission and in the transmitter itself, which resulted in a considerable increase of speed combined with greater reliability. The instrument in this form remained in use for nearly 30 years, but the developing needs of the public for a more rapid news service led him to make further improvements, and in 1902 he patented the apparatus now in use. The column printer was also his invention, his first patent for this being taken out in 1880. Among his other numerous inventions are an automatic transmitter for the tape machines, the "annunciator"—a machine in use in the smoking-rooms, etc., of the Houses of Parliament which indicates in large letters the name of the member speaking and the subject of the debate—and the first public fire alarm system used in the streets of London. He was elected an Associate of the Institution in 1873 and a Member in 1877, and served on the Council in 1877-8.

PETER EMIL HUBER was born in 1836 in the town of Zürich. He died in Zürich on the 4th October, 1915. Amongst electrical engineers he was best known as the managing director, and founder, of the Oerlikon Machine Works; though his direction of that great establishment was but a part of his claim to their regard. From a memorial pamphlet issued by his family, containing details of his education and career, we learn the following particulars. He was schooled at Lausanne, and in 1855 on the foundation of the celebrated Federal Polytechnicum at Zürich he entered as one of its first students in the engineering side. Leaving the Polytechnicum he gained practical experience in the famous establishments of Sulzer in Winterthur and of Escher Wyss in Zürich. He sought to improve his training by professional sojourn in England and in Belgium. In 1867 with some of his friends he founded at Oerlikon in the outskirts of Zürich a mechanical engineering establishment under the style of P. E. Huber and Company. This undertaking after various turns of fortune was in 1876 reconstructed and merged in the great establishment now known as the Oerlikon Machine Works. Until 1885 these works were chiefly occupied in the manu-

\* *Journal I.E.E.*, vol. 27, p. 246, 1898.

† *Ibid.*, vol. 30, p. 270, 1907.

fracture of machine tools and heavy milling machinery; but from that date onwards the development of electrical machinery became the principal occupation of the undertaking. Huber was managing director until the end of 1894, and was President of the body of Directors down to 1911. How ably and unweariedly he worked for the success of the firm, how heartily he threw himself into efforts for the promotion of the progress and welfare of his native city and of his country, his fellow-citizens and fellow-countrymen have testified in glowing terms. He had a penchant for architecture, and was much trusted for advice respecting public buildings. For a short period he was connected with the management of the Industrial Museum in Zürich. For many years he was an active member of the district board which controls the public works of Zürich, and took the leading part in the improvement of the public quays, the introduction of tramways, and the provision of public lighting. He will be remembered to all time for the part which he took in the organization, at the Frankfort Electrical Exhibition of 1891, of the now historical demonstration of the transmission of power from Laufen on the Neckar (near Heilbronn) to Frankfort. This project, originated by Engineer Oskar von Miller of Munich, was to prove that it was possible economically to transmit 100 horse-power to a distance of 100 miles. This was a demonstration on a much greater scale than anything previously attempted. Upon its success or failure hung the projects for the harnessing of Niagara and other transmission propositions. Huber threw himself into the matter with characteristic energy, and in co-operation with Director Rathenau of the Allgemeine Elektrizitäts Gesellschaft of Berlin, the great experiment was carried to a successful issue. Incidentally, the demonstration also established the successful operation, for long-distance transmission projects, of the 3-phase system of alternating currents. The machinery and transformers were supplied in part by the Oerlikon Company, and in part by the A.E.G. In the sequel this demonstration brought much business to the Oerlikon Works, which became a chief seat for the development of power plant and electric traction plant, and played an important rôle in equipping the tramways and electric railways of Switzerland and other countries. Another undertaking which owes much of its development to the genius of Huber is the aluminium works of Neuhausen. In 1887 he became head of a preliminary company to exploit the Héroult patents, and in 1888 he founded with others the Aluminium Industry Company which successfully created the aluminium works of Neuhausen, Rheinfelden, Land-Gastein, and lastly of Chippis in the Canton Valais. In this last undertaking he took, as President, an intense interest. One of the latest acts of his life was to visit these great works on their completion, and with his youngest grandchild to climb up to Riffelalp. He was one of the founders of the Society known as the Verein Schweitzer Maschinen-Industrieller, a body which has done much to consolidate the interests of the engineering concerns in Switzerland, and he was its president from its foundation until his death. In 1864 he married Anna Maria Werdmüller, who predeceased him by four years. He was made a Colonel and Brigade Commander in the Swiss Artillery, and a member of the Artillery Commission. Executive, capable, essentially upright in all his dealings, he commanded universal

respect. Personal ambitions and pride of influence were conspicuously absent from his character. Jealous of no man, he trusted his friends and was trusted by them. He was elected a Foreign Member of the Institution in 1889, and a Member in 1911. S. P. T.

HERBERT KINGSFORD joined the electrical staff of the Telegraph Construction and Maintenance Company in the early seventies and, after serving on several expeditions, transferred his services to the Anglo-American Telegraph Company, on board their cable steamer *Minia*. During this time he also acted as cable engineer for the Canadian Government in connection with their cable system in the Gulf of St. Lawrence and around the Maritime Provinces. When the Commercial Cable Company started, he took charge of the electrical department on board their cable steamer *Mackay Bennett* while she was in commission. In 1886 he was appointed engineer to the Central and South American and Mexican Telegraph Companies, and continued in their service (later as superintendent) until his death, which occurred on the 5th February, 1916. His principal contributions to the art of submarine cable testing are the modification of the Varley loop test, using uneven bridge arms, and the modification of the Blavier test. The first is an excellent and accurate method of determining the position of a fault in short lengths of cable; in the other case he pointed out the basic principle that the current through the fault must be maintained constant whether the distant end is freed or earthed. He was also patentee of an electrical grapnel to indicate when the cable is hooked, as well as of a special form of wedge grip to secure the cable quickly at the bows. He was a man of original and trenchant ideas, vigorously and clearly expressed, widely read and travelled, full of anecdotes of the fast disappearing generation of cable pioneers, and he will be much missed by a wide circle of business and social friends on the West Coast of South America as well as elsewhere. He was elected an Associate of the Institution in 1876 and a Member in 1886, and from the latter year until his death he acted as Local Honorary Secretary for Peru.

A. D.

FREDERICK WILLIAM LACEY was born in 1856. He served his pupilage under a leading London architect and subsequently was engaged on civil engineering work in South America for some three years. In 1882 he was appointed engineer and surveyor to the Brentford Council, but also continued his private practice as an architect. In 1889 he was appointed engineer to the Bournemouth Corporation, and this appointment was subsequently extended to include that of borough architect. During the period he held the above position he was responsible for the reconstruction of the main drainage, subsidiary and surface draining of Bournemouth, the remaking of the main roads, the building and enlargement of refuse destructors, the auxiliary water supply and pumping station, the construction of the whole of the tramway permanent way, and other engineering works incidental to his position. He was also responsible for the laying out of Meyrick Park, Queen's Park, King's Park, the East Cemetery, the West Overcliffe Drive, and the Undercliffe Drive. His more important architectural works were the

Municipal College, the new Law Courts, the East Cemetery church, the three fire stations, and the designs for the proposed pavilion which have recently been sanctioned by the Local Government Board. He was elected an Associate of the Institution in 1898, an Associate Member in 1899, and a Member in 1909.

E. M. L.

ROBERT SAMUEL LLOYD, a director of Messrs. Hayward-Tyler and Company, died at his residence at St. Albans on the 23rd September, 1915, after a painful illness of several months. He was the son of William Lloyd, M.D., of Birmingham, whose father was the head of Lloyds' Bank in the early part of last century. After a training in engineering work, commenced in Switzerland and continued at works in Wednesbury, he joined the firm of Hayward-Tyler and Company in 1877 and was for many years managing partner (or director) of their Luton works. He designed and carried out many important works of electrical and water engineering, among others the first experimental installation of the Edison electric light on Holborn Viaduct. The firm's workshops in London were, if not the first, one of the first works in England to be lighted on this system, and much valuable experience was gained in the experiments conducted there. He was elected an Associate of the Institution in 1883, and a Member in 1894.

FREDERICK GURR MACLEAN, C.I.E., who died from heart failure on the 12th December, 1915, at Woking, was born in 1848 and educated at a private school. After studying electricity with special reference to telegraphy under the late Sir William Preece he was appointed by the Secretary of State for India to the Telegraph Department in India, where he arrived at the beginning of 1869. In September 1879 he was employed on telegraph work in connection with the military operations in Afghanistan for which he was awarded the Afghan medal; and the valuable services he rendered on this occasion were brought to the notice of the Government of India. As a superintendent he subsequently held charge with conspicuous success of many important districts in different parts of India and was appointed Director of Construction in January 1896. On the retirement of Mr. C. E. Pitman, C.I.E., in 1900 Mr. Maclean was appointed to succeed him as Director-General of Telegraphs, India. Under his administration the Telegraph Department experienced a great expansion in its activities; a large amount of construction was undertaken and more modern and faster systems of working introduced generally on the main lines. In recognition of his services he was awarded the honour of "Companion of the Indian Empire" on the occasion of the Durbar held at Delhi in January 1903 to celebrate the coronation of King Edward VII. At the close of that year he left India and retired, to the universal regret of his brother officers amongst whom he had throughout been extremely popular. He had a wonderfully even placid disposition and a temper that was rarely if ever ruffled. In his youth he was an excellent rider and fond of sport of all kinds. He leaves a widow and one son, Captain F. A. Maclean, 109th Baluchis Regiment, Indian Army, who was severely wounded in France early in the war and is now attached to the Royal Scots Fusiliers at Jhansi in India. He was elected a Member of the

Institution in 1876 and was Chairman of the Calcutta Local Centre in 1901-2.

M. G. S.

HENRY ALEXANDER MAVOR was born at Stranraer in 1858 and was educated at St. Matthew's School, the Glasgow and West of Scotland Technical College, and Glasgow University. In the early days of electric lighting he founded the firm of Messrs. Muir and Mavor (now Messrs. Mavor and Coulson, Limited). This firm carried out much of the pioneer electric lighting work in Scotland, and among others an electrical installation for lighting the Glasgow General Post Office. This installation was subsequently extended to various municipal buildings, shops, and offices. In 1892 the generating stations were taken over by the Glasgow Corporation and formed the nucleus of the Glasgow electricity supply undertaking of to-day. Mr. Mavor then directed his energies and his inventive resources to the design and manufacture of electrical machinery, and took a prominent part in the electrical developments of the last 25 years. The latest important work which engaged his attention was the problem of electric propulsion of ships, and many patents on this subject are evidences of his inventive fertility. His experimental work on a practical scale included the equipment of a vessel of 2,000 tons with electric propelling machinery. The value of his work in this connection has had wide recognition both from electrical engineers and from naval architects, and his last two visits to America were made in the capacity of consultant to the company which equipped the United States Navy collier *Jupiter* with electric propelling machinery. The long series of papers which he contributed to the transactions of several Institutions show the varied and active character of his scientific and technical interests. As a Governor of the Royal Technical College, Glasgow, Chairman of the Glasgow Branch of the Board of Trade Committee on Juvenile Employment, a member of the Executive Committee of the Engineering Employers' Federation, and in other spheres, Mr. Mavor found scope for his organizing capacity, and for his deep interest in educational and social problems. His relations with his employees were exceptionally cordial, and among those with whom he came into contact his loss will be that of a valued friend. Endowed with a singularly alert and penetrating intellect, and with a gentle, sympathetic, and generous nature, he attracted to himself a very wide circle of friends. To them he was known as a man of versatile talent, broad culture, and refined tastes, with an extensive knowledge and fine appreciation of literature, music, and art. He was a skilful draughtsman, and found recreation in sketching, painting, and modelling. He died on the 16th July, 1915. He was elected a Member of the Institution in 1890, and was Chairman of the Glasgow Local Section in 1902-3.

GEORGE ALFRED NEALE died on the 20th March, 1916, at the age of 49 years. He was the son of the late John Neale, telegraph engineer to the North Staffordshire Railway. He obtained an appointment with the Hull and Barnsley Railway Company about 20 years ago, and remained in the service of that Railway as signal and telegraph superintendent until his death. He was elected a Member of the Institution in 1901.

**THOMAS PARKER** was born in December 1843, and died on the 5th December, 1915. He entered the service of the Coalbrookdale Company at an early age and remained with them for 10 years. The next 14 years were spent in Birmingham and Manchester, where the evening classes and lectures enabled him to supplement his earlier education and to study scientific and technical subjects. He returned to the Coalbrookdale Company about 1876, and for six years occupied positions of increasing responsibility; during this period he had for a time charge of the company's electro-depositing department and built his first dynamo, which was used for electroplating. In 1882 he met and entered into partnership with the late Mr. Paul Bedford Elwell, their intention being to manufacture accumulators, with which Mr. Parker had been experimenting for some time. The manufacture of dynamos was soon added, and in 1884 the firm of Elwell-Parker, Limited, was registered, and took over the business. At this period he designed and built a multi-phase alternator with a stationary armature and revolving field of the salient-pole type, each phase being intended to supply a Jablochokff candle. The general design was practically the same as that of the modern alternator. In 1884 the electric generating plant and car equipments for the Blackpool tramways were built. The firm's works continued to extend, and in 1889 became merged in the Electric Construction Corporation, of which Mr. Parker was the works' director and chief engineer for the next five years. At the beginning of this period the works at Bushbury, Wolverhampton, were established, and a large number of contracts were undertaken for the equipment of electricity supply stations. Electric traction also claimed much attention; during these years the Bournbrook section of the Birmingham tramways was equipped with accumulator cars, the first section of the South Staffordshire tramways was electrified on the overhead trolley system, and the Liverpool Overhead Electric Railway was built. He always took a keen interest in electrochemistry and electrometallurgy. When the Cowles process for the manufacture of aluminium bronze was first brought out, he considered the use of continuous current to be a mistake, and designed an alternating-current furnace; this was tried and proved a success. Later on he used the alternating-current furnace for the manufacture of phosphorus, and, in conjunction with Dr. Readman, worked out a commercial process which soon displaced the older methods of phosphorus manufacture. He became managing director of Thomas Parker, Limited, in 1894, and held that position for some four or five years. Afterwards he engaged in consulting practice, his principal work being the electrification of the Metropolitan Railway, he having previously acted as one of the two assessors in the tribunal appointed by the Board of Trade to decide upon the system to be adopted. He was a director of the Metropolitan Railway Company for some years. He was elected a Member of the Institution in 1885. J. H. W.

**SIR ARTHUR WILLIAM RÜCKER, F.R.S.**, died on the 1st November, 1915. He was born in 1848 at Clapham and was educated at Clapham Grammar School and Brasenose College, Oxford. After taking his degree he became demonstrator in physics to Professor Clifton at the Clarendon Laboratory. In 1874 he was appointed Professor of Mathematics and Physics at the Yorkshire College, Leeds,

where he devoted considerable attention to research and also took an important part in the development of the College. In 1886 he became Professor of Physics at the Royal College of Science, London, a position which he held until 1901, when he was appointed Principal of the University of London. He was knighted in the following year. During the seven years he was Principal considerable changes took place in the constitution and work of the University, amongst others, the incorporation of University College and King's College. He retired in 1908. He was elected a Member of the Institution in 1882, and served on the Council in 1887. He was a Fellow of the Royal Society, was awarded a Royal Medal in 1891, acted as one of the secretaries from 1896 to 1901, and from time to time contributed papers to the *Transactions* of the Society. In 1901 he was president of the British Association, having previously served as treasurer and as president of Section A.

**GUSTAVE P. SELIGMANN-LUI** was born at Épinal in the Vosges in 1855. After two years at the École Polytechnique he entered in 1877 the Government Telegraph Department. In view of the threatened shortage of gutta-percha—a subject considered at the Electrical Congress in connection with the Paris Exhibition of 1881—the Minister of Posts and Telegraphs decided to dispatch an official of his Department to the Far East, with the object of studying on the spot the production of rubber and the cultivation of the tree which produces it, and his choice fell on M. Seligmann-Lui. As a result of a visit to Sumatra, Cambodia, and Siam, M. Seligmann-Lui came to the conclusion that in spite of certain difficulties it was feasible to establish plantations of rubber trees in Cochinchina; but the scheme was not persevered with. On his return he took in hand the preparation and publication of a translation of Clerk Maxwell's work on "Electricity and Magnetism"; and some years later he completed a translation of Dr. Alexander Russell's book on the "Theory of Alternating Currents." At the end of 1889 he was sent, together with one of his colleagues, M. de la Touanne, to report on the telephone industry in the United States. In 1894 he was appointed chief engineer of the Paris telephone service, and in 1901 he became Inspector-General of Posts and Telegraphs, a position which he held until his death. He was particularly interested in military applications of telegraphy and telephony, and as a military telegraph officer since 1878 he took part in its development and organization. In recognition of his services in this respect, he was promoted in 1906 to be Officer of the Legion of Honour, his professional services having been previously recognized in 1887 by the award of the Cross of Chevalier. At the outbreak of war in 1914 he took up his post as Director of Military Telegraphy at Headquarters, and in November of the same year he received from the hands of the President of the French Republic the Cross of Commander of the Legion of Honour. He died on the 9th December, 1915. He was elected a Foreign Member of the Institution in 1880 and a Member in 1911.

**ROBERT HENRY SMITH** was born in Scotland in 1851, and was educated at Edinburgh. On leaving the University in that city he served his apprenticeship with Messrs. Tennant and Company, of Leith. On completing

his apprenticeship he was for a short time in the drawing-office of Sir Joseph Whitworth and Company, and afterwards in the works of Johann Zimmerman, of Chemnitz, and the drawing-office of Wohler and Company, of Berlin. In 1874 he was appointed Professor of Engineering in the University of Japan, a position which he held for four years. After a short time in Italy he accepted in 1881 the post of Professor of Civil and Mechanical Engineering at Mason's College, Birmingham. On retiring in 1896 from that position he engaged in consulting work for a number of years, carrying out many electric lighting and tramway schemes. During recent years he devoted considerable attention to literary work, writing many articles for the technical Press and publishing a number of books. He died on the 18th February, 1916. He was elected a Member of the Institution in 1893.

**CHARLES ERNEST PAOLO DELLA DIANA SPAGNOLETTI**, a Past President of the Institution, died at his house in Hampstead on the 28th June, 1915, in his eighty-third year. Thus has passed away one of the last of the early landmarks along the road of the application of electric science to the use and convenience of man, a pioneer in the development of electrical signalling on railways, and a prominent figure in the Institution from the time that it was the Society of Telegraph Engineers—for he was elected a member within a year of its foundation. On leaving school Mr. Spagnoletti at the early age of 14 served for some months in the Actuary's Department of the National Debt Office. We next find him holding an appointment under Alexander Bain, helping him to develop his printing telegraph which was the prototype of the Wheatstone automatic system, being actuated by contacts controlled by a strip of paper with punched perforations. In the year 1847 was founded in Lothbury the Electric Telegraph Company, and the young Spagnoletti, then a boy of 15, entered its service, and remained with that company, rising so much in efficiency and importance that at the age of 23 he was appointed chief of the Telegraph Department of the Great Western Railway, with whom it may be said that practically his whole career was spent. Immediately on his appointment Mr. Spagnoletti set himself to develop the complete system of block signalling and railway working which, first applied on the Great Western Railway, was soon adopted by the Metropolitan and District Railways, and practically laid the foundation of block signalling which in various forms has been in use on almost every railway in the Kingdom. It was in connection with the extension of his system to the working of the Metropolitan and District Railways that he in 1865 invented and introduced his disc block instrument for controlling the heavy traffic on those lines; and, soon after, finding that the effects of lightning were detrimental to the safe working of the system, weakening and even occasionally reversing the signals, he introduced his well-known induction device known all over the world as the "Spagnoletti Induced Needle," which has been and still is being fitted to thousands of single-needle instruments.

Mr. Spagnoletti held the position of Electrician to the Great Western Railway for nearly 40 years, and during that time his active brain and inventive genius were constantly at work producing invention after invention and

improvement after improvement in every department of railway telegraphy and train signalling. In the course of his duties on the Great Western Railway he designed a portable telegraphic apparatus which was always carried on the train in which Queen Victoria travelled to Scotland, by which telegraphic communication could be established at any point on the route, so as to be able to summon immediate help in the event of a breakdown or for any other cause. Mr. Spagnoletti had this apparatus under his charge, and necessarily always travelled by the Royal train. He also devised automatic apparatus in connection with swing-bridges on the Great Western Railway, whereby it was rendered impossible for trains to pass over until those bridges were in their proper position. In addition to many inventions for the electrical locking of signal levers, he designed apparatus by which the signalman in advance can control the working of the signals in the rear, so as effectually to prevent trains being sent on until the line is clear. He also invented the well-known Spagnoletti fire alarm for town service, of which many were fixed in the streets of London, and of which it is not too much to say that they were as efficient as they were unsightly. When the first electric railway in this country was established in 1889—the City and South London Railway—Mr. Spagnoletti was appointed Consulting Electrical Engineer to the line, advising on the mechanical and electrical plant and devised apparatus in various forms for ensuring the safe working of the system.

Mr. Spagnoletti was elected a Member of the Institution (then the Society of Telegraph Engineers) in 1872, being proposed by the late William T. Ansell and seconded by the late Sir Charles Bright. He served on the Council from 1874 to 1880, and was then elected a Vice-President, which office he held until 1884. In 1885 he was elected President, and at the January meeting of that year he delivered his inaugural address, which took the form of a general review of the progress of electrical science and its applications to industry up to that date. Mr. Spagnoletti does not appear to have contributed any original papers to the Proceedings of the Institution, but he frequently took part in the discussions, and in this way the Institution derived considerable benefit from his knowledge and experience. Thus he contributed to the discussions on induction between wire and wire, on earth currents and electric storms, on the protection of telegraphic apparatus from lightning discharge, on lightning conductors, on electrical interlocking of railway signals, on railway telegraphs, and on the Siemens system of railway gong signalling. He also spoke in discussions upon electric lighting questions, in which he had some rather special experience in connection with railway work, and upon the lighting of ships by electricity. In 1912 the Council conferred upon him the special honour of making him an Honorary Member of the Institution.

Mr. Spagnoletti was a Member of the Institution of Civil Engineers, of the Physical Society, of the Royal Society of Arts, of the Imperial Institute, and of several other scientific bodies. He was a member of the International Jury on Electrical Exhibits at the Exposition Universelle at Paris in 1878 and a member of the Congress held at Paris in 1881 in connection with the Exposition d'Électricité. He was also a juror and a member of the Committee of the Health Exhibition held in London in 1884 and of the Inventions Exhibition in 1886, and he was a member of the General

and Executive Committees of the Chicago Exhibition in 1893. "

Mr. Spagnoletti was born in London on the 12th July, 1832, and was descended from the noble Neapolitan family Della Diana, who had considerable estates both in the kingdom of Naples and in Sicily. His grandfather, Paolo Ludovico della Diana, was not only a great musician and violinist but a most remarkable man, for at the age of 12 he astonished the Conservatoire at Naples by his mastery of the violin and by his extraordinary musical genius. Not long after this he was taken to Spain as a musical prodigy, where he had great success, and on his return to his native country they dubbed him "Il Spagnoletto," and this becoming his professional name, he obtained permission from the Papal Court to change his name to Spagnoletti. After performing at Milan he was brought to London, where he was engaged for several years as second violinist at the King's Theatre, ultimately becoming the leader of that orchestra. He was a composer of some eminence, and was the leader in oratorios, the Philharmonic concerts, and at the great Musical Festival in Westminster Abbey. Reference has been made here to the career of this remarkable man for two reasons: First to show the origin of the name Spagnoletti, and second because it accounts for many of the qualities which were so conspicuous in his grandson, Mr. Spagnoletti, who all his life had been musical and who had a charming tenor voice. Some of the older members of the Institution may remember the historic evening at the Institution when Sir William Preece showed the first Edison phonograph at the February meeting of 1878. Mr. Spagnoletti sang into the instrument a well-known song and finished up the demonstration by singing into the phonograph the National Anthem, Sir William Preece remarking that "Mr. Spagnoletti's melody might be kept for a hundred years, say until 1978, when the sounds would be reproduced as 'God save the Queen' sung by Mr. Spagnoletti before the Society of Telegraph Engineers in England in 1878." Mr. Spagnoletti both composed and wrote songs, and of many of the songs of Wilhelm Ganz and of William Wrighton the words were written by him.

Mr. Spagnoletti had outlived most of his colleagues and contemporaries, but those who had the privilege of his friendship will ever remember that he brought a beam of sunshine into whatever company he might be found. Although well past four-score years of age, there was nothing old about him. His tall, slim, almost youthful figure made him appear 20 years younger. His mind was always young; and, as he possessed both a good memory and a keen sense of humour, he had a remarkably extensive repertoire of good stories. His conversation, always interesting, and sparkling with wit and merry tales made his company enjoyable. Among his more intimate friends he was always affectionately known as "Spag." Mr. Spagnoletti was always ready to give to younger members of the profession his help and encouragement, and many of them who are now no longer young will remember with gratitude the pleasant evenings at his house in Aberdeen Place where science and music alternated with bright conversation in which he was the life and soul of the party. The world is all the poorer by the loss of such a man, for his cheery disposition was always with him even to within

a few days of his death, and such men and such friends can never be replaced.

Mr. Spagnoletti left two sons and three daughters to deplore his loss. One son, Mr. James E. Spagnoletti, has been for 30 years a member of the Institution, and one of his daughters was married to the son of Sir William Crookes, O.M., and recently President of the Royal Society, but she became a widow shortly after her father's death. Mr. Spagnoletti was buried in the family grave in Hampstead Cemetery. C. W. C.

HERBERT ARNAUD TAYLOR was born in August 1841 and died on the 23rd December, 1915, at the age of 74 years. He was educated privately and passed into the Royal Military Academy, Woolwich, obtaining his commission as Lieutenant in the Royal Engineers in 1862. Resigning his commission he became a pupil of the late Mr. Latimer Clark in 1867. In this way his career as a civil engineer was begun, his main work being connected with the design, manufacture, and laying of submarine cables. At the time of his death he was senior partner in the firm of Clark, Forde, Taylor and Erskine-Murray, and in connection with his firm he acted as engineer to the majority of the submarine cable companies. The first important work of this nature upon which he was engaged was the Persian Gulf Cable of 1868, Latimer Clark being the engineer appointed by the British Government to carry out the operations. Subsequently he acted as engineer for the laying of the 1873 and 1874 Anglo-Atlantic cables and for many of the Eastern and Associated Companies' cables in the East and on the African coast. Indeed, his whole life and interests were devoted to the subjects intimately connected with submarine cables. He was instrumental in the development of duplex working on cables, the introduction of automatic transmission on cable circuits, and later, in association with Mr. S. G. Brown, in the invention of the drum cable-relay and magnetic shunt, both of which have contributed so largely to the improved working of long cables; in fact he was prominent in all the notable advances made in submarine cable work during the past 40 years. He was a member of the British Association Committee for constructing and issuing practical standards for use in electrical measurements, and also of the Subcommittee on Cables which was appointed by the Engineering Standards Committee. In connection with the standard of electromotive force, viz. Clark's standard cell, his investigations and experiments were undoubtedly of great value, and the assistance rendered was gratefully acknowledged by his colleague and partner Latimer Clark. In addition to the varied work entailed by his active participation in the cable enterprises entrusted to his firm, a large amount of interesting experimental work was carried out. In 1899 he gave evidence before the Pacific Cable Committee, and afterwards his firm of Clark, Forde and Taylor were appointed engineers for the British and Colonial Governments, the cable being made and laid to the specifications for which he was in the main responsible. He was elected a Member of the Institution in 1872 and served on the Council from 1897 to 1900. A. L. D.

ERNEST GEORGE TIDD, Captain in the Highland Light Infantry, was born at Norwood, Surrey, on the 29th June, 1857, and received his early education at

New College, Eastbourne, and at Neuchâtel, Switzerland. He received his electrical training at the Hanover-square College, London. He became an Associate of the Institution in 1889, and was transferred to full membership in 1898. He was the eldest son of George Tidd, of the firm of F. A. Tidd and Company, members of Lloyds, London. He married on the 2nd December, 1893, Helen Kate Bond. Captain Tidd was in his early days employed by Messrs. Paterson and Cooper, and went to Glasgow to represent them. He afterwards entered the business of Messrs. Morris Warden and Company, eventually becoming a partner in the firm. When the Glasgow Local Section of the Institution was formed, he was appointed its first Honorary Secretary, and after seven years' work his services were so appreciated that the local members presented him with a handsome service of silver, and in 1909 he was Chairman of the Local Section, following Lord Kelvin in the Chair. Captain Tidd was for many years an enthusiastic Volunteer, and when the Territorial Force was formed, he continued his services in his Regiment—the 6th Battalion of the Highland Light Infantry. He was gazetted Captain in 1908, and, at the time of his death, was due for his majority. The outbreak of war found him with his Regiment, and from that time to May 1915 his Regiment was employed in training and defending a portion of the East Coast of Scotland. He was sent to Egypt in May 1915, and afterwards to the Dardanelles. He met his death on the 13th July at Cape Helles, gallantly leading his company and exhibiting the greatest bravery; and even when mortally wounded, with great unselfishness he cheered on and encouraged his men. Busily occupied as he was, he yet found time for many hobbies. He was a keen motorist and enthusiastic amateur gardener. His various occupations naturally gave him a wide circle of friends, and his loss will be deeply regretted by those who were drawn to him by his kindly disposition and unselfish nature. He is survived by his wife and only son, who was gazetted to the same regiment as his father in 1913, and was in Gallipoli at the time of his father's death. J. K. S.

FREDERICK HENRY VARLEY died in London on the 12th March, 1916, at the age of 74 years. He was the youngest son of Cornelius Varley—scientist and artist and one of the founders of both the Microscopical and Water Colour Societies. With his brother Octavius, Mr. F. H. Varley fairly early in his career became a manufacturer and patentee of various electrical appliances. Together they produced cable-testing, A. B. C., needle, and other telegraph instruments, whilst carrying out for the late C. F. Varley (an elder brother) a considerable amount of special experimental work, notably the "musical telephone" and various electrical meters. An interesting patent was taken out about this time by Mr. F. H. Varley for a static apparatus in compact form for the production of sparks for gas lighting or amusement, described as the "electric wand." This apparatus seems to have sold in considerable numbers and probably was a forerunner of modern electrostatic gas lighters. The firm became contractors for the postal telegraph services, during this period manufacturing such

articles as double-current keys and galvanometers, whilst Mr. F. H. Varley devised and patented a railway block signalling system which found favour with several railway companies. The style "O. & F. H. Varley" was maintained by Mr. Frederick Varley for a long time after his brother's decease. He spent some time upon an electrical target apparatus—a French patent—for indicating the result of scores instantaneously at the firing-point and obviating the employment of a marker in the danger zone. Practical tests were carried out at Northwood at a range of 1,000 yards with satisfactory results, but for some reason or other, possibly the complicated wiring necessary, the invention did not secure permanent military attention. About the year 1884 he introduced and patented the use of flexible carbon—a woven fibre specially treated and carbonized—at that time considered to be a step in advance towards the better distribution and maintenance of arc lighting. Its special convenience lay in the fact that it could be produced in considerable lengths and wound on spools. Its character admitted of low-amperage lighting and long running without renewal in the special lamp designed by Mr. F. H. Varley for its consumption. Electric filament lamps of the same material and known as the "Varley diaphanous filament" lamp were also introduced, but unfortunately certain indispensable details of the manufacture of glow lamps were then covered by other patentees and, although useful results were secured, the new lamp had to be abandoned. So far as can be remembered, Mr. F. H. Varley's inventions and patents include the use of carbon pencils *in vacuo* for arc lighting; variable carbon resistances both of flexible and solid carbon plates or discs; primary and secondary batteries with porous carbon electrodes; an alternating and direct-current motor combination for mixed traction systems; various types of telephones and wireless telegraph apparatus. Recently he devoted himself to the commercial development of the tuned reed wireless system of Mr. A. T. Johnson, which he assisted to bring to a practical stage some time before the great war cut short all private enterprise in this direction. He was a constant attendant at the meetings of the Institution, of which he became a Member in 1872.

T. A. V.

HERBERT BRANDON WHITE was born in 1869. He was the son of the late Mr. Henry Brandon White of Highgate, for many years connected with the Gunmakers Company. He received his technical training at the Finsbury College, whence he proceeded in 1892 to Messrs. James Pitkin and Company. Later he became a partner in the firm, but in 1911 he withdrew from the business and established his electrical department as a separate concern under the title of the White Electrical Instrument Company. Here he invented and improved many electrical measuring instruments, being associated in this direction with many of the pioneers of the electrical profession. Like his father he was a member of the Gunmakers Company, holding office as Master only a year or two ago. He died on the 23rd December, 1915. He was elected a Member of the Institution in 1911.

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## EXPLANATION OF ABBREVIATIONS.

- (p) indicates a reference to the general title or subject of a paper or address.  
 (p) indicates a reference to a subject dealt with in a paper or address of which the title is not quoted.  
 (d) indicates a reference to a discussion upon a paper or address of which the general title or subject is quoted.  
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